2nd International Conference on Circularity, Sustainability and Resilience in Water, Wastewater and Sludge Management (CSRW26)

29/03/26 - 01/04/26

Thessaloniki, Greece

BOOK OF ABSTRACTS

Institute of Sustainable Water Management and Water Law

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of the 2nd International Conference on Circularity, Sustainability and Resilience in Water, Wastewater and Sludge Management (CSRW26) Thessaloniki, Greece, 29 March-1 April, 2026

Beneficiary of the ISBN number:

Prof Ioannis Katsoyiannis for EPLO (European Public Law Organization)

Kolonaki Premise 16, Achaiou St. 10675, Athens. Greece

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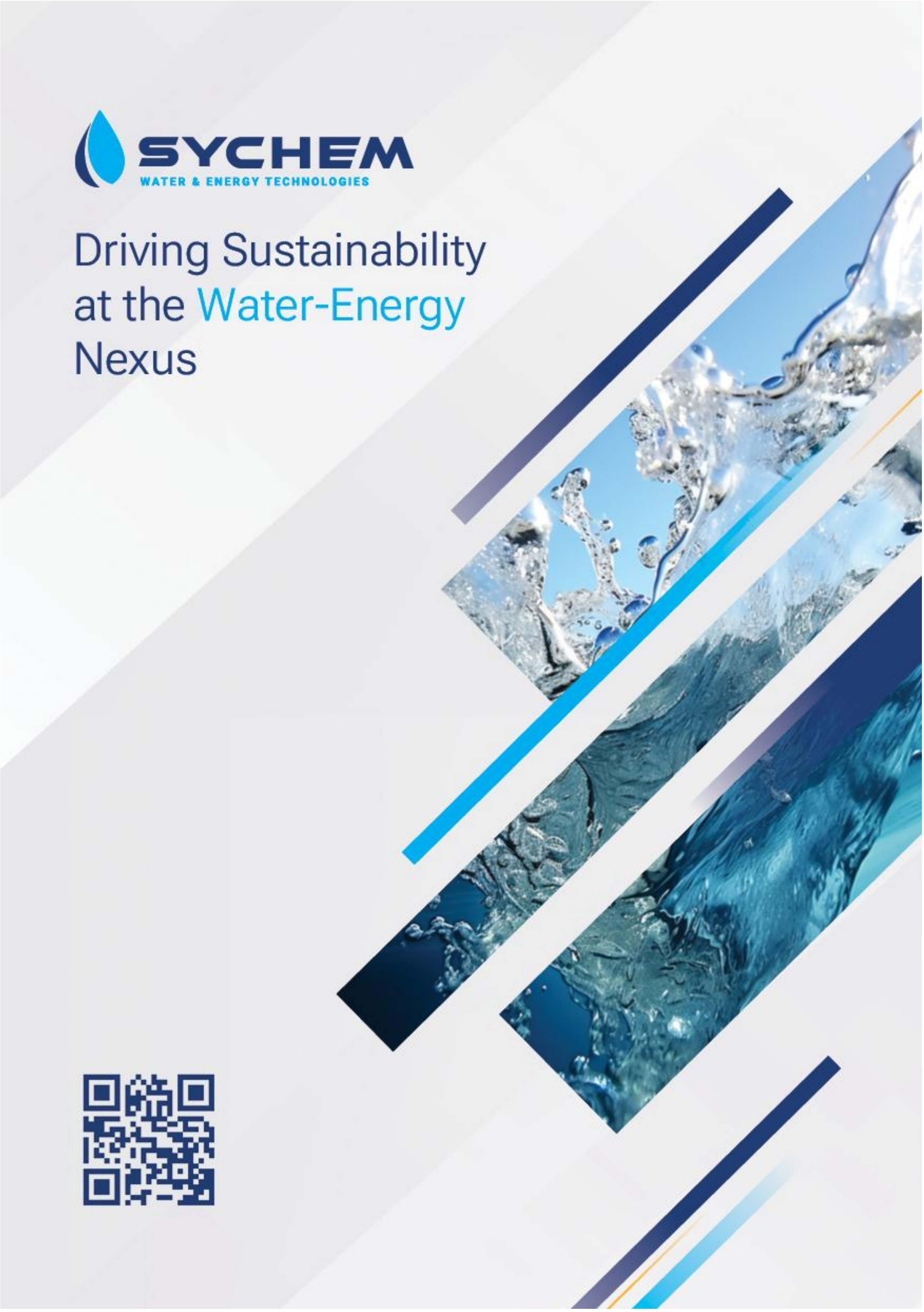
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WASTEWATER

Advances in Membrane and Redox Processes for Sustainable Water and Wastewater Treatment: Insights from Research for Development Projects

Konstantinos V. Plakas, Sotiris I. Patsios, Dimitris C. Sioutopoulos, Vasilis Ch. Sarasidis, Panagiota Petsi, Anthoula Karanasiou, Anastasios J. Karabelas

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Breakthrough technological developments in water/wastewater treatment are essential to ensure a climate-resilient water future by addressing global societal threats and challenges, such as: a) increasing water scarcity (necessitating water reuse and desalination), b) achieving millennium development goals (ensuring global access to high-quality freshwater and sanitation), c) depletion of raw materials (requiring the recycling of metals, nutrients, minerals, and value-added chemicals from water/wastewater), d) man-made environmental pollution (demanding advanced treatment of municipal and industrial, potentially toxic, wastewater), and e) biodiversity loss (resulting from wastewater discharges, organic micropollutants, endocrine disruptors, salinization, and water scarcity). To tackle these challenges, the NRRE lab at CPERI/CERTH has been conducting applied and fundamental research on advanced physicochemical and biological processes to develop viable and sustainable state-of-the-art water/wastewater treatment technologies that reduce pollution, conserve energy, and utilize renewable energy and other natural resources. This lecture presents insights from related R&D projects carried out within European and national programs, as well as services provided to industry, with emphasis on emerging membrane technologies, advanced redox processes and their hybrids with membranes, and the development of sustainable bio-based processes for the efficient valorization of biological resources in a sustainable and circular manner.

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Adsorptive behavior of tin-based novel coagulants for hexavalent chromium removal

Athanasia K. Tolkou[1], Sanjay Kay Sagar[1,2], Eirini Moschou[1], Dimitris Koulos[1], Ioannis A. Katsoyiannis[3], Sabrina Sorlini[2], George Z. Kyzas[1]

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Hexavalent chromium (Cr(VI)) is a highly toxic and carcinogenic pollutant commonly found in industrial wastewater, posing serious environmental and health risks. Conventional treatment methods often face challenges in achieving effective Cr(VI) removal under varying pH conditions. Coagulation is a widely applied technique for the removal of heavy metals, mainly through destabilization and aggregation, but coagulants with adsorptive properties can significantly improve the performance. In this study, the effectiveness of novel tetravalent tin-based coagulants, i.e. Cs@Sn, ST@Sn, and PVS@Sn, were compared with $SnCl_4$ and chitosan (Cs), starch (ST) and polyvinyl alcohol (PVA) biopolymers for Cr(VI) removal. Batch experiments showed that $SnCl_4$ achieved almost complete removal (99.7–100%) at all pH levels tested, while Cs@Sn reached 98.5%, with the addition of 50 mg/L of coagulant with respect to the metal. The superior performance of Cs@Sn suggests a combined mechanism where conventional coagulation is complemented by surface adsorption interactions of the coagulant with Cr(VI) species, enhancing binding beyond simple destabilization. These results demonstrate that tin-based coagulants offer a robust, pH-tolerant approach for Cr(VI) remediation.

Acknowledgements:

We acknowledge support of this work by the project “Hybrid technologies of smart membranes and novel materials for the removal of hexavalent chromium from water” (ΥΠ3ΤΑ-0560800) which is implemented under the action “SUB1.1: Clusters of Research Excellence” of the sub-action “Strategy for Excellence in Universities & Innovation” (ID 16289), Greece 2.0 – National Recovery and Resilience Fund and funded by European Union Next Generation EU.

A Comparative Assessment of Duckweed Grown in Different Types of Agricultural Wastewater for Mineral Phytoextraction

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Common duckweed (Lemna minor L.) is an aquatic macrophyte that forms compact surface canopies and is characterized by efficient nutrient uptake, making it a strategic agent for re-capturing essential minerals from contaminated wastewaters for sustainable agriculture. This study evaluated the growth and nutrient removal performance of duckweed in soilless tomato greenhouse wastewater (GW) and vertical farming wastewater (VFW). To this end, fresh nutrient solutions (FNS) at varying electrical conductivity (EC) levels (1/4X to 2X) were compared to determine the optimal growth parameters. The highest uptake efficiency was observed at the lowest EC level (1/4X) in FNS, where duckweed achieved significant depletion of nitrate (NO_3^-), phosphorus (P), potassium (K), magnesium (Mg), as well as micronutrients including iron (Fe), manganese (Mn), copper (Cu), and boron (B), with removal rates ranging from 83% to 100%. Increasing ionic strengths of FNS gradually suppressed nutrient depletion efficiency of duckweed, particularly in macronutrients. Consequently, 1X FNS was selected as the control treatment for comparison with GW and VFW. While biomass grown in VFW exhibited the highest N accumulation (42 g kg^{-1}), plants cultivated in FNS showed the greatest P concentration, exceeding those grown in GW and VFW by approximately 145% and 65%, respectively. Biomass cultivated in FNS was particularly effective in micronutrient recovery, exhibiting approximately 3-fold higher Fe and Mn concentrations, among others. Although duckweed grown in GW accumulated lower concentrations of macro- and micronutrients in general, the highest dry weight was achieved in this media. Overall, these results highlighted the potential of duckweed as a promising strategy for recovering resources from agricultural effluents while simultaneously producing nutrient-rich biomass for circular bioeconomy.

Keywords: agriculture, bioeconomy, duckweed, phytoremediation, wastewater

UVB mediated photolysis of gliclazide: Evaluation of degradation kinetics in different aquatic systems

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An increased consumption of antidiabetic drugs such as gliclazide, which are only partially removed in conventional wastewater treatment plants (WWTPs) has been observed, due to the growing prevalence of diabetes [1]. As a result, gliclazide is one of the Type 2 diabetes pharmaceuticals detected in WWTP effluents and natural waters [2], highlighting its persistence and the need for effective removal technologies.

This study examines the degradation of gliclazide via UVB-mediated persulfate activation as an advanced oxidation process. A design of experiments methodology was applied to optimize operational parameters, including persulfate concentration and pH, with respect to removal efficiency. Results show a pseudo-first-order kinetic profile (R2>0,99) with the rate constant (k1) determined to be k1 = 0,06169 min-1 and a half-life of 11,2 min under optimized experimental conditions. The influence of typical water constituents (nitrate, carbonate, and humic acid) was subsequently evaluated. In addition, the process performance was assessed in real water matrices, namely WWTPs effluents.

The obtained results demonstrate that UVB-activated persulfate effectively enhances gliclazide degradation, although matrix components significantly affect reaction kinetics, underlining the importance of realistic water conditions.

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Tracing Pharmaceuticals from Wastewater to Food Crops

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Water scarcity accelerates interest in the reuse of treated municipal wastewater for agricultural irrigation. There are concerns about pharmaceuticals and personal care products (PPCPs) from recycled wastewater entering soil and food crops. This study evaluates the removal and potential health risks of PPCPs associated with wastewater reuse under pilot-scale conditions.

A pilot-scale quaternary treatment unit was operated at a municipal wastewater treatment plant (211,000 p.e.). The treatment train consisted of coagulation, ultrafiltration, GAC adsorption, and UV disinfection. The post-treatment unit produced irrigation water compliant with Class A requirements from EU Regulation 2020/741. Concentrations of 118 pharmaceuticals, illicit drugs, and metabolites were monitored in tertiary-treated wastewater, reclaimed irrigation water, soils, and crops using in-line SPE–LC–MS/MS.

Quaternary treatment achieved compound-specific PPCP reductions of up to 74%, resulting in low ng/L residual concentrations in reclaimed water. Field experiments using drip irrigation were conducted on potatoes, carrots, onions, and parsley. Only 12 PPCPs were detected above quantification limits in soils and crops. Telmisartan and carbamazepine showed the highest accumulation, predominantly in soil and leaf tissues, while uptake into tubers remained limited.

A human health risk assessment based on the Threshold of Toxicological Concern (TTC) indicated no unacceptable risks for adults or children. Estimated consumption levels required to exceed TTC values were far above typical dietary intake.

Overall, the results demonstrate that irrigation with reclaimed wastewater meeting EU quality standards can be safely applied to food crops with minimal PPCP-related health risks. The findings support wastewater reuse as a viable climate adaptation strategy, while highlighting the importance of quaternary treatment and field-based monitoring of emerging contaminants.

Acknowledgement

This research was funded by the Slovak Research and Development Agency under the contract No. APVV-22–0292.

Sustainable Water Reuse from Steel Wastewater through Direct Contact Membrane Distillation (DCMD) Supported by Thermodynamic and Scale-Up Modeling

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Steel manufacturing generates large volumes of saline wastewater, and conventional treatment technologies often fail to achieve high recovery or enable effective water reuse. Direct Contact Membrane Distillation (DCMD) is a thermally driven process capable of utilizing low-grade waste heat, offering a promising route toward high-quality water production and near zero-liquid-discharge operation.

In this work, DCMD performance was evaluated using an integrated approach combining thermodynamic simulations (PHREEQC) to assess solution behavior and scaling risk, laboratory experiments with a hollow-fiber polypropylene membrane module, and a predictive model for process performance. Synthetic wastewater representative of steel industry effluents was treated at feed temperatures of 40–60 °C and flow velocities of 0.05–0.5 m/s.

The experimental results demonstrated consistent permeate fluxes between 1.4 and 4.8 $kg \cdot m^{-2} \cdot h^{-1}$, salt rejection exceeding 99.9%, and stable operation without membrane wetting or fouling at recoveries up to 93%. Model predictions showed strong agreement with measured fluxes and outlet temperatures, with mean absolute percentage errors below 5% and coefficients of determination greater than 0.96. Parametric simulations indicated that increasing feed temperature and crossflow velocity enhances water productivity and reduces the membrane area required to produce 1 $m^3 \cdot day^{-1}$ of permeate.

These findings highlight the potential of DCMD coupled with industrial waste heat to significantly reduce freshwater demand and wastewater discharge in steel production. The approach supports industrial sustainability objectives and demonstrates applicability to broader water- and energy-intensive industries.

Acknowledgements:

The Authors acknowledges the financial support of the EU Horizon under the projects CORNERSTONE "Combined technologies for water, energy, and solute recovery from industrial process streams" (HORIZON-CL4-2023-TWIN-TRANSITION-01-40, Grant Agreement No. 101072449) and the MELODIZER "Sustainable membrane distillation for industrial water reuse and decentralised desalination approaching zero waste" (HORIZON-CL4-2022-RESILIENCE-01-14, Grant Agreement No. 101091915).

Anaerobic Digestion of Fermentation Waste Biomass

Lívia Švorcová, Barbora Jankovičová, Tomáš Lukáč, Miroslav Hutňan

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Anaerobic treatment of waste biomass represents a promising approach for the valorization of biodegradable waste with the aim of renewable energy production and reduction of environmental impacts. In the case of waste biomass from fermentation-based production, special attention must be paid to its specific composition and to potential inhibitory effects on anaerobic processes.

Waste biomass from fermentation production can be classified as a substrate with a high content of organic matter (COD – chemical oxygen demand), which makes it suitable for anaerobic treatment. The anaerobic degradation is further supported by a relatively high ratio between organic solids (loss on ignition) and COD, reaching a value of 2.04. The C/N ratio of 4.6 classifies this substrate as nitrogen-rich. Due to the high contents of nitrogen and sulfur in the waste biomass, certain problems could be expected during anaerobic treatment, particularly related to ammonia and, especially, sulfide inhibition of anaerobic processes.

Biogas potential tests demonstrated good anaerobic biodegradability of the waste biomass; however, during long-term anaerobic treatment, sulfide inhibition can be expected. This inhibition was also reflected in a relatively low conversion of COD to methane. Therefore, this study further presents the results of long-term monitoring of an anaerobic reactor treating this waste biomass, including a gradual increase of the organic loading rate up to a value of 1.5. Sulfide inhibition was suppressed by the addition of $FeCl_3$, and the results summarize reactor operation and process performance under increasing organic loading conditions.

Acknowledgement

This research was supported by the Slovak Research and Development Agency under the contract No. APVV-22-0292.

Role of matrix components during oxidative water treatment

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Oxidative water treatment has been applied since more than a century for disinfection and abatement of micropollutants in water and wastewater treatment. In the last decades, a lot of kinetic and mechanistic information was obtained for transformation reactions of micropollutants and naturally abundant bromide, iodide and nitrite. This information is key to assess the roles of matrix components during oxidative treatment. To this end, the dissolved organic matter (DOM) plays a crucial role because it consumes the largest fraction (typically > 90%) of chemical oxidants applied in water treatment and leads to ensuing products. The complexity of DOM does not warrant simple mechanistic studies similar to individual compounds and a suite of parameters needs to be determined such as the oxidizable site concentration, electron donating capacity, and precursor concentrations for oxidation byproduct formation. These parameters can be assessed by novel methods including oxidative titrations, dye-based measurements of electron abstraction from DOM, tagging of reactive sites and product identification during oxidative treatment (including stable isotope composition). Such information can also lead to constitution of synthetic matrices to mimic realistic treatment conditions. Furthermore, the reactivity of DOM with secondary oxidants formed during oxidative water treatment needs to be determined for an enhanced understanding of product formation.

This talk will start with a general assessment of reactivity of chemical oxidants with inorganic and organic compounds for micropollutant control. Thereafter, it will provide new insights for the understanding and quantification of reactive sites of DOM and the ensuing consequences for oxidant stability and formation of oxidation byproducts and their fate in post-treatment processes. Furthermore, formation of oxidation byproducts in the presence of bromide (iodide) and nitrite will be discussed.

Keywords:

Ozonation, micropollutants, dissolved organic matter, bromide, iodide, nitrite, oxidation byproducts, biodegradability

Lemon Peel- based Carbon Quantum Dots Combined with Graphitic Carbon Nitride (g-C3N4-CQD) as Photocatalytic Material for the Degradation of Emerging Contaminants

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The conversion of agricultural wastes into materials for different applications is an innovative and sustainable solution for the management of wastes and promotion of circular economy. In this study, lemon peel wastes from lemon processing plant were obtained for the production of biochar via pyrolysis at 300 ºC under N2 atmosphere. From the biochar, carbon quantum dots (CQDs) were hydrothermally synthesized at 220 ºC for 4 hours. On the other hand, graphitic carbon nitride (g-C_3N_4) was obtained via polymerization of urea at 500 ºC for 4 hours. To obtain the g-C_3N_4-CQD composite, 20 mL of CQD solution was mixed with 1 g of g-C_3N_4, sonicated, and dried. The final material was characterized accordingly by UV-Vis/DRS, fluorescence and ATR-FTIR measurements. The materials synthesized were used for the degradation antidiabetic drugs (a class of emerging contaminants) in water under visible light. CQDs alone did not work for the photodegradation of antidiabetic drugs (metformin, pioglitazone, dapagliflozin, glimepiride, gliclazide and glimepiride). The g-C_3N_4-CQD composite worked well for all the contaminants except for metformin. The photodegradation rates for gliclazide and repaglinide using g-C_3N_4 alone and the g-C_3N_4-CQD composite were compared under different water matrices (ultrapure, lake, river, and wastewater treatment plant effluent). Gliclazide had photodegradation rate ranges of 0.00223 – 0.01302 min-1 and 0.00291 – 0.01887 min-1, using g-C_3N_4 and g-C_3N_4-CQD, respectively, with highest degradation rates in ultrapure water. The half-life of gliclazide under different water matrices ranged 53.2 – 310 min and 36.7 – 238 min, using g-C_3N_4 and g-C_3N_4-CQD, respectively. On the other hand, repaglinide had photodegradation rate ranges of 0.01203 – 0.01511 min-1 and 0.01249 – 0.02573 min-1, using g-C_3N_4 and g-C_3N_4-CQD, respectively, with highest degradation rates in ultrapure water. The half-life of repaglinide under different water matrices ranged 42.5 – 57.6 min and 26.9 – 55.5 min, using g-C_3N_4 and g-C_3N_4-CQD, respectively. This study shows the potential of the lemon peel waste- based material for the photodegradation of emerging contaminants. Future work includes the identification of radicals involved in the photodegradation.

Sustainable orange peels/aluminum@graphene oxide composites for efficient removal of synthetic dyes from textile wastewater

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The discharge of dye-containing wastewater from textile industries poses significant environmental challenges due to the persistence, toxicity, and complex composition of synthetic dyes. In this study, sustainable aluminum modified orange peels functionalized with graphene oxide (OP-Al-GO) were synthesized and evaluated for the removal of methylene violet (MV) and reactive red 120 (RR120) from aqueous solutions. The adsorption kinetics were found to follow a pseudo-second-order model, while isotherm analysis revealed a Langmuir behavior for MV and Freundlich behavior for RR120. The OP-Al-GO composites exhibited improved removal efficiency for both dyes (64.8% for RR120 and 96.2% for MV) at pH 3.0, compared to orange peels (OP), orange peels/aluminum (OP-Al) and graphene oxide (GO), due to the synergistic effects of bio-derived carbon, aluminum and graphene oxide. High removal efficiency was maintained in binary dye mixtures, with OP-Al-GO achieving dye removal of 96.9% MV and 85.7% RR120, reflecting the robustness under complex conditions. Furthermore, the proposed adsorbent was tested on real wastewater samples and the results highlight OP-Al-GO as a viable and versatile adsorbent for textile wastewater treatment, capable of achieving high adsorption removal and meeting the challenges of multi-component dye wastewaters.

Diclofenac and amoxicillin removal from wastewater using fruit peels as natural adsorbents

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The discharge of wastewater contaminated with pharmaceutical compounds from hospitals, clinics, and other medical facilities can cause severe ecological damage due to their toxicity, particularly when present at high concentrations. In this study, 100% natural fruit peels, namely lime (LP), orange (OP), kiwi (KP), fig (FP), and pomegranate (PP) peels, were investigated as low-cost adsorbents for the removal of diclofenac (DCF), an anti-inflammatory drug, and amoxicillin (AMX), an antibiotic, from aqueous solutions. All adsorbents exhibited their highest removal efficiencies for both DCF and AMX at pH 3.0. Among the tested materials, natural fruit peels were especially effective for DCF removal, with kiwi peels (KP) achieving the highest removal efficiency (98.9%). The most promising materials were further modified with magnesium (KP-Mg and FP-Mg), resulting in significantly enhanced performance, particularly for AMX removal (65.1 %). In all cases, maximum adsorption was attained within a short contact time of 15 min. Kinetic and isotherm models were applied to elucidate the adsorption behavior. Overall, the results demonstrate that natural fruit peels are economical, eco-friendly, and efficient adsorbents, supporting circular-economy principles by valorizing food waste into sustainable materials for water treatment.

Removal of triclosan from aqueous solution using activated carbon derived from chestnut as waste biomass

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Triclosan (TCS) is an antimicrobial agent belonging to the bisphenol class, widely used in healthcare applications and, in particular, in personal care products (PCPs). It is classified as an emerging pollutant frequently detected in aquatic environments and is known to exhibit toxicity toward certain aquatic organisms as well as adverse effects on the male reproductive system. Its increasing occurrence and associated risks highlight the need to investigate effective removal mechanisms, such as adsorption. In this study, bio-based activated carbon was prepared from chestnut shell as waste biomass (ACChS) using KOH for activation and pyrolysis at 400 °C (ACChS_400 °C) and 500 °C (ACChS_500 °C) for 1 h. The prepared adsorbents were evaluated for their efficiency in TCS removal. The effects of pH, contact time, initial TCS concentration, and adsorbent dosage were examined. According to the results, ACChS_400 °C exhibited superior performance, achieving an equilibrium at 30 min, a removal efficiency of 98.8%, and an adsorption capacity of 69 mg/g at pH 3.0, outperforming ACChS_500 °C. Kinetic and isotherm models were also applied to elucidate the adsorption behavior. Overall, the results demonstrate that activated carbon derived from chestnut shells is a promising, low-cost adsorbent for the effective removal of triclosan from aqueous solutions.

Growth Performance and Nutrient Removal of Microalgae Cultivated under Suspension, Immobilized and Encapsulated Systems in Synthetic Wastewater

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The use of immobilized microalgal cells has attracted increasing interest due to their ability to enhance biomass growth and protect cells from adverse external factors, including contamination and predation by competing microorganisms [1]. In this study, immobilization and encapsulation strategies were investigated to evaluate their effect on microalgal growth and nutrient removal from synthetic wastewater under controlled laboratory conditions. Experiments were conducted in sterilized 1 L batch culture flasks using synthetic wastewater simulating municipal effluent, with the following characteristics: COD 890 mg/L, NH_4–N 61 mg/L, total nitrogen (TN) 85.4 mg/L, and total phosphorus (TP) 14.8 mg/L. Three microalgal strains were examined: Chlorella sorokiniana, Algir sp., and Monoraphidium sp. For each strain, three cultivation modes were evaluated, including suspended cells, cells immobilized on commercial carriers, and encapsulated cells [2]. K3 biocarriers were used with 500 m^2 m^{-3} specific surface area and 25 × 10 mm diameter/depth, and microalgal cells were allowed to attach to the carrier surfaces. Cell encapsulation was performed using sodium alginate at a concentration of 2% (w/v). After complete dissolution of the alginate in the cell suspension, the liquid was added dropwise into a calcium chloride solution, resulting in the formation of calcium alginate beads. In both immobilized and encapsulated systems, the solid phase represented 10% (v/v) of the total working volume. Cultures were inoculated to reach an optical density of OD_{680} = 0.30–0.35 to ensure consistent initial biomass among all experimental units. Cultivation was performed under continuous cool white illumination at 112 μmol m^{-2} s^{-1}, with temperature maintained at 22–23 °C, pH between 6.7 and 8.4, and aeration supplied at 0.75 L min^{-1}. Sampling was carried out at certain time periods for measurement of microalgal growth via optical density at 680 and 750 nm, cell counting by microscopy, and dry cell weight (DCW). Nutrient dynamics were assessed by measuring ammonium, total nitrogen, and total phosphorus concentrations [3]. Encapsulated cells demonstrated improved performance during the early stages of cultivation, exhibiting enhanced growth and a pronounced reduction in ammonium and total phosphorus concentrations compared to suspended cells. These findings highlight the potential of immobilization and encapsulation strategies for improving microalgae-based wastewater treatment and biomass production.

Acknowledgements:

This research was funded by the EU European Research Executive Agency (REA), project NAMOR PN 101182365. The views and opinions expressed are, however, those of the authors only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor REA can be held responsible for them.

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Hydrodynamic Cavitation-Based Treatment of Saline Wastewater Containing Reactive Red 120 and Congo Red

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Textile wastewater is typically characterized by high salinity and the presence of persistent azo dyes, which significantly limit the effectiveness of conventional treatment processes. In this study, hydrodynamic cavitation (HC) was evaluated as an advanced oxidation approach for the degradation of Reactive Red 120 (RR120) and Congo Red (CR) under saline conditions representative of textile effluents. Experiments were performed in a 14 L recirculating HC system equipped with a Venturi constriction, operated at an inlet pressure of 4 bar and controlled temperature. Initial dye concentrations were 15 mg L^{-1} for RR120 and 10 mg L^{-1} for CR. The effect of pH (2–7), oxidant type, oxidant dose, and salinity were investigated. HC alone resulted in limited decolorization, achieving approximately 35% removal for RR120 and 22% for CR after 120 min at pH 2. The addition of oxidants markedly enhanced degradation efficiency. Under acidic conditions, RR120 removal reached up to 96% with both hydrogen peroxide (H_2O_2) and sodium persulfate ($Na_2S_2O_8$). In contrast, CR degradation was strongly oxidant-dependent, with persulfate achieving up to 94% decolorization, compared to 69% with H_2O_2. Saline conditions were simulated using NaCl at a concentration of 2.5 g L^{-1}. The presence of chloride ions reduced degradation rates and final removal efficiencies, with RR120 decolorization decreasing to 81–86%, depending on the oxidant used, indicating radical scavenging effects. Persulfate-based systems showed greater tolerance to increased salinity and maintained high removal efficiency over a wider pH range compared to H_2O_2. Overall, the results demonstrate that oxidant-assisted hydrodynamic cavitation is a promising and flexible treatment strategy for saline dye-containing wastewaters. The findings highlight the importance of oxidant selection and operating conditions for optimizing cavitation-based processes and provide useful insights for future scale-up and practical implementation.

LC-HRMS strategy for suspect and untargeted discovery of emerging contaminants in wastewaters

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Suspect and non-target screening strategies based on high-resolution mass spectrometry (HRMS) offer a powerful and comprehensive framework for the investigation of emerging contaminants (ECs), facilitating the detection, prioritization, and identification of a broad spectrum of chemical substances in complex matrices. Wastewater represents a critical monitoring point for ECs, as it integrates chemical inputs from urban, industrial, and domestic sources and reflects both environmental exposure and treatment efficiency. Herein, wastewater influent and effluent samples were collected from the Sindos Wastewater Treatment Plant (WWTP) during the winter period (October 2025–February 2026). Sample preparation involved two parallel procedures using weak anion exchange (WAX) cartridges for the extraction of per- and polyfluoroalkyl substances (PFAS) and hydrophilic–lipophilic balance (HLB) cartridges for a broad range of other ECs. Analyses were performed using liquid chromatography coupled to an Orbitrap high-resolution mass spectrometer. Suspect screening was based on an extended suspect list including more than 2500 compounds and transformation products (TPs), compiled from literature data and laboratory-produced TPs. Non-target analysis was conducted using optimized data processing workflows in Compound Discoverer, including feature detection, molecular formula prediction, spectral library matching (mzCloud), and in silico fragmentation tools. Suspect screening resulted in the detection of more than 100 compounds, while non-target analysis enabled the identification of more than 30 additional compounds. Representative identified compounds included pharmaceuticals (e.g., acetaminophen, ampicillin, atenolol, atorvastatin, azithromycin, carbamazepine, cetirizine, citalopram, clarithromycin, codeine, diclofenac, febuxostat, and furosemide), industrial markers (benzotriazole), personal care and antifungal agents (climbazole), and illicit drugs (cocaine). Several TPs were also tentatively identified, indicating ongoing degradation processes during wastewater treatment. High detection frequencies were observed for most compounds, suggesting their ubiquitous presence in both influent and effluent samples. Most compounds were assigned at confidence level 2a, while several were confirmed at level 1 using reference standards, highlighting the effectiveness of LC-Orbitrap-HRMS combined with suspect and non-target workflows for comprehensive environmental monitoring and evaluation of treatment performance in wastewater systems.

Acknowledgements

The research project was supported by European Commission under the HORIZON-WIDERA- TWINNING BOTTOM-UP within the framework of the SPECTRA project (Grant No 101158453).

From Crisis to Policy: advancements of Wastewater Epidemiological Surveillance in EU under the Revised Urban Wastewater Treatment Directive

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Wastewater-based epidemiology (WBE) has emerged as a lasting public health instrument in the European Union, evolving from an emergency-driven application during the COVID-19 crisis into a regulated surveillance component under the Revised Urban Wastewater Treatment Directive (UWWTD). The recast Directive explicitly recognizes urban wastewater as a strategic medium for monitoring public health parameters, aligning environmental policy with the One Health framework and strengthening EU-wide preparedness for future health threats. Within this policy transition, the EU-WISH project (EU Wastewater Integrated Surveillance for Public Health) plays a central role in translating scientific advances into harmonized, operational surveillance practices across Member States. The focus of EU-WISH is to support activities to strengthen and improve national capacities for wastewater public health surveillance by enhancing knowledge exchange and sharing best practices based on scientific evidence.

Building on evidence from Thessaloniki, Greece—a long-standing WBE observatory with continuous monitoring since the early phase of the pandemic—this study illustrates how local-scale implementations can inform EU-level policy design. Thessaloniki has served as a reference site for evaluating the reliability, interpretability, and public health value of wastewater signals under real-world conditions characterized by climate variability, sewer system stresses, and population dynamics typical of large Mediterranean cities. The results demonstrate how interpretation of wastewater viral loads enhances consistency with medical surveillance data and supports early public health awareness during epidemic waves. Beyond epidemiological trend detection, wastewater monitoring in Thessaloniki has contributed to timely insights on infection dynamics and viral circulation at population scale, reinforcing confidence in WBE as a decision-support tool rather than a purely research-driven activity. These experiences directly inform the implementation logic of the UWWTD, particularly regarding surveillance frequency, data robustness, and integration with public health authorities.

Overall, the Thessaloniki case, embedded within the EU-WISH framework, exemplifies the shift “from crisis to policy”: wastewater surveillance is no longer experimental, but an institutionalized component of EU public health infrastructure, capable of supporting coordinated, climate-resilient, and forward-looking health protection strategies.

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Dechlorination, Heavy Metal Removal, and Calcium Preservation Technology for Municipal Solid Waste Incineration Fly Ash

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Dechlorination pretreatment has always been a prerequisite for the resource utilization of MSWI fly ash, but there is relatively little attention paid to the simultaneous efficient detoxification and value enhancement of fly ash pretreatment products. This study proposes a two-step pretreatment process combining carbonation and ultrasonication assisted with washing to systematically investigate its effects on dechlorination, calcium retention, and heavy metal stabilization. Results showed that carbonation promoted the formation of more stable calcium carbonate, achieving preliminary calcium fixation. Washing experiments demonstrated that heavily carbonated fly ash treated with citric acid, ammonium bisulfate, and ethylenediaminetetraacetic acid exhibited soluble chlorine contents of 1.20%, 1.23%, and 1.37%, with corresponding calcium loss rates of 15.72%, 12.72%, and 14.63%, respectively. However, ethylenediaminetetraacetic acid washing caused leaching concentrations of heavy metals to exceed regulatory limits, making it unsuitable for carbonated fly ash. The introduction of ultrasonic pretreatment further enhanced dechlorination and calcium retention. The soluble chlorine contents decreased to 0.76%, 0.86%, and 0.83%, and calcium loss rates were 14.63%, 10.82%, and 11.45%, respectively. Moreover, in the citric acid and ammonium bisulfate systems, all heavy metal leaching concentrations met their standard limits. RAC risk assessment further confirmed that, compared to the sharp increase in risk induced by ethylenediaminetetraacetic acid, the combined “carbonation-ultrasonication” with citric acid or ammonium bisulfate washing effectively controlled the environmental risk of heavy metals. This study successfully established a technical pathway centered on “carbonation-ultrasonication-washing (with citric acid or ammonium bisulfate)”, providing a feasible solution for turning hazardous fly ash into a valuable resource.

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Holistic Water And Waste Water Management In Mining Activities – The Example Of The New Thrace Mine Project

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The qualitative and quantitative management of water associated with mining activities constitutes a core pillar of Eldorado Gold's sustainability strategy. It integrates best practices for reduction, reuse, recycling, recovery, and disposal, ensuring that the water balance and ecosystem in the areas where the company operates are not disrupted.

The planned new "Thrace Mine" project, at the Perama Hill deposit, developed by Thracean Mines S.A., a subsidiary of Eldorado Gold in Greece, will implement practices focused on the proper management of liquid waste, enhanced environmental sensitivity, and rational water balance management.

In all cases—whether concerning waste management or the overall management of water quantities regardless of their origin (surface water, contact water, collected or diverted water, process water, groundwater), as well as the associated natural receivers—all these are integrated into a comprehensive, holistic management system. The objective is to maintain the regional water balance and preserve biodiversity within the project's area of activity. Water balance management initiatives focus on ensuring uninterrupted operation of the activity while safeguarding overall water resources and natural receivers. At the same time, liquid waste generated by the activity is treated, recycled, and reused. All these actions are implemented through the holistic water and waste management plan, supported by modern systems and techniques to be presented.

Eldorado Gold's strategy for natural water resource management and biodiversity conservation in Greece guarantees the development and implementation of best practices and inovative technologies in the new Thrace Mine project, demonstrating that modern mining activity can align with environmental responsibility and set standards for the responsible development of natural resources.

Keywords: Water Management, Recycling, Protection of Surface and Groundwater, Liquid Waste

Mining Waste Management – The Current Situation And The Next-Day Perspective In The Mining Industry In Greece

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Mining waste management constitutes a fundamental pillar of Eldorado Gold Corp.'s sustainability strategy, incorporating best practices for the reduction, reuse, recycling, recovery, and rehabilitation of mining waste disposal areas.

The "Kassandra Mines," operated by Hellas Gold S.A. ., a subsidiary of Eldorado Gold Corp., represent one of the most significant mining projects in Europe and include the Olympias, Skouries, and Stratoni sub-projects in NE Halkidiki, Greece.

In the same direction, the planned new "Thrace Mine" project, concerning the Perama Hill deposit of Thracean Mines S.A., also a subsidiary of Eldorado Gold Corp. in Greece, will implement waste management practices with enhanced environmental sensitivity.

In both cases, key initiatives include the implementation of dry-stack tailings technology, which minimizes environmental footprint, enhances safety, and accelerates landscape rehabilitation. Additional features include specifications incorporating modern sealing systems, continuous monitoring, and advanced water management infrastructure.

The Kokkinolakkas Mine Waste Management Facility (KTMF) is a reference project with a total storage capacity of 10.85 Mm^3. It is a facility that manages, with maximum environmental protection standards, not only the mining waste generated by the Olympias and Mavres Petres operations, but also materials resulting from the removal, cleaning, and restoration of all old disposal sites and intervention areas accumulated from long-standing historical mining activity, with priority given to their remediation.

The Perama Mine Waste Management Facility (MWMF) will receive and manage approximately 10.3 Mt of waste materials with differing qualitative characteristics, reflecting variations in mineral raw materials and operational processes.

Recycling initiatives focus on the use of tailings as backfill material in underground mining excavations, while waste rock materials are reused in construction works. Furthermore, the company has established the largest plant nursery in Greece and, in connection with the new project, is developing a Black Pine (a rare endemic species of the area) nursery in the Perama region. This supports the rehabilitation of the mining landscape using native species and contributes to the sustainability of this particular species.

The waste management strategy of the Kassandra Mines and Eldorado Gold Corp. in Greece provides assurance for the development and implementation of best practices and state-of-the-art technologies in the new Thrace Mine project as well, demonstrating that modern mining activity can align with environmental responsibility and set standards for responsible natural resource exploitation and land restoration.

Keywords: Mining waste, Dry-Stack Tailings, Environmental Management System, Sustainability

Anti-Scaling Membrane Distillation Crystallization for Gypsum and Water Recovery from Industrial Wastewater

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Recovering gypsum ($CaSO_4$.2H2O) from industrial wastewater streams is often challenging due to membrane scaling and operational instability in conventional separation processes, such as nanofiltration (NF), and reverse osmosis (RO). Membrane Distillation Crystallization (MDCr), which integrates water purification with controlled mineral crystallization, has emerged as a promising alternative. In this study, MDCr was applied to a synthetic calcium sulfate solution to evaluate its ability to simultaneously recover high-purity gypsum and high-quality water without fouling or scaling on the membrane.

Experiments were conducted at feed temperatures of 40 50, and 60°C using a hydrophobic hollow-fiber membrane. Process performance was evaluated through permeate flux and permeate conductivity measurement at different operating temperatures. The results demonstrate that high water recovery (>80%) can be achieved from this industrial wastewater without membrane scaling, while higher feed temperatures resulted in increased permeate flux due to the increase in the thermal driving force. No flux decline was observed with recovering a high purity of gypsum, indicating stable membrane performance and effective suppression of scaling and fouling phenomena. In addition, permeate conductivity remained consistently low (<5.1 $\mu S\ cm^{-1}$), confirming the production of a diluted water and excellent salt rejection (~99.99%).

Overall, the findings demonstrate that membrane distillation crystallization offers a robust and energy-efficient approach for simultaneous water recovery and gypsum crystallization. The scaling-free operation and strong temperature-flux dependence highlight the potential of MDCr as a viable alternative to conventional membrane processes in applications where scaling presents a critical limitation.

Acknowledgement:

The Authors acknowledge the financial support of the EU Horizon under the projects CORNERSTONE "Combined technologies for water, energy, and solute recovery from industrial process streams" (HORIZON-CL4-2023-TWIN-TRANSITION-01-40, Grant Agreement No. 101072449).

Enhanced Boron Rejection in Reverse Osmosis for Boron-Rich Wastewaters: Insights from Zeta Potential and Particle Size Analysis under Polyol and Salinity Effects

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Efficient boron removal remains a major limitation in seawater reverse osmosis (SWRO) desalination and becomes even more challenging in industrial effluents treatment, where boron concentrations often exceed 5 mM. Despite their industrial relevance, boron-rich wastewaters remain insufficiently studied and the concentration dependent chemistry governing boron separation is poorly understood. In this study, boron removal from high boron feedwater (80 mM) was investigated using a FilmTec SWRO30 membrane operated at a constant recovery of 5% and pressure up to 40 bar, while examining the effects of polyol complexation and salinity under membrane compatible pH conditions (pH 4-10). Under high salinity conditions (30 g L^{-1} NaCl), boron rejection reached 98.42% at pH 10, driven by enhanced electrostatic exclusion associated with borate formation, as confirmed by an increase in zeta potential to -16.9 mV and unchanged particle size. In contrast, mannitol addition enabled comparable rejection of 98.83% at pH 8, through formation of large, negatively charged boron-mannitol complexes, increasing particle size to approximately 200 nm and induced a zeta potential of -7.33 mV. Overall, the results reveal two distinct rejection mechanisms: electrostatically dominated separation under high salinity and steric size exclusion driven by polyol complexation. Importantly, polyol-assisted boron removal at near neutral pH 8 provides a sustainable, membrane compatible pathway for efficient boron removal in both SWRO and boron rich industrial wastewaters, avoiding the operational drawbacks associated with extreme pH.

Comprehensive SCIEX LC–MS/MS Solution to Meet EU Drinking Water Directive Requirements

Carlos Bueno

Antisel

The European Union Drinking Water Directive 2020/2184 introduces stricter quality requirements and expands the list of regulated and emerging contaminants in drinking water, including pesticides, pharmaceuticals, PFAS, bisphenol A, nonylphenol, and cyanotoxins. This presentation outlines an integrated analytical strategy to support regulatory compliance using advanced LC–MS/MS technologies. Emphasis is placed on simplified, high-throughput workflows based on direct injection, minimal sample preparation, and harmonized chromatographic conditions. The use of SCIEX QTRAP platforms enables sensitive and selective quantification across a wide polarity range, while MRM and MRM^3 approaches enhance confidence in trace-level identification. Method performance is demonstrated through validation data covering sensitivity, linearity, accuracy, precision, and robustness in multiple water matrices. The proposed solutions allow laboratories to efficiently monitor all LC-MS amenable parameters defined in the Directive using a limited number of methods, columns, and mobile phases, supporting routine, unattended operation. Overall, the approach provides a practical and future-proof framework for drinking water surveillance under the new European regulatory landscape.

Fe-zeolite for the Removal of Arsenic from Waters

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Arsenic contamination has become a serious issue for both environmental and public health worldwide (Isaev et al., 2025). Elevated concentrations of arsenic, particularly in its inorganic oxyanion forms As(III) and As(V), have been documented in groundwater across Asia, North and South America, and parts of Europe, mainly due to geochemical processes such as weathering, mineral dissolution, and redox-controlled geochemical reactions, as well as anthropogenic activities including mining, combustion of fossil fuels, excessive use of arsenic-based pesticides and herbicides, and various industrial discharge (Gong et al., 2023). Iron-based materials, such as ferrihydrite, goethite, hematite, nanoscale zero-valent iron, and Fe(III)-loaded composites, are widely recognized for their strong affinity and selectivity toward inorganic arsenic species (Hao et al., 2018; Gong et al., 2023; Isaev et al., 2025). Despite their excellent performance, the large-scale application of these materials is often limited by high production costs, variable environmental stability, and challenges with post-treatment recovery and reuse (Ghosh et al., 2025). Consequently, increasing attention has focused on naturally occurring low-cost mineral adsorbents such as zeolites, which are abundant, inexpensive, and easily modified (Poorkhalil et al., 2025). Thus, Fe-zeolite composite (FeZ) was prepared by co-precipitation and assessed as an adsorbent of As(V) from aqueous solutions. Detailed structural and surface characterization (SEM/EDX, XRD, Mössbauer spectroscopy, FT-IR, N2 adsorption-desorption, and magnetic susceptibility) confirmed the successful incorporation of highly dispersed γ-Fe_2O_3 nanoparticles within the clinoptilolite type zeolite framework, creating a material with enhanced surface reactivity and improved textural and magnetic properties.

Batch experiments were conducted to evaluate the effects of pH, ionic strength, initial As(V) concentration, contact time, and temperature. As(V) uptake was strongly pH-dependent, with maximum adsorption under acidic conditions, while ionic strength showed negligible influence. This behavior demonstrates that inner-sphere Fe–O–As complexation represents the predominant adsorption mechanism, complemented by electrostatic attraction at low pH. Equilibrium data were best described by the Freundlich isotherm (R^2=0.99), indicating a heterogeneous distribution of high-affinity Fe-oxide sites, with a maximum adsorption capacity of 31.1 mg/g. Kinetic behavior followed the pseudo-second-order model (R^2=1.00), confirming chemisorption as the rate-controlling step, while intraparticle diffusion analysis revealed a multistep mass-transfer pathway. Thermodynamic parameters indicated an endothermic, entropy-driven process consistent with ligand-exchange reactions on Fe-oxide surfaces. Overall, these findings demonstrate that FeZ is a promising, low-cost adsorbent with strong potential for removing As(V) from aqueous solutions.

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Circular agro-waste derived biochar solutions for urea-based herbicides removal in agricultural runoff and landfill leachate

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The widespread consumption of dates generates large amounts of date seed waste, particularly in arid regions, and its conversion into biochar provides a circular economy based solution for herbicide removal from wastewater. In this study, date seed biochar was evaluated for the removal of the urea-based herbicides linuron and isoproturon from agricultural runoff and landfill leachate. The synthesized biochar was characterized by BET and FTIR techniques. High removal efficiencies of 88.2% for linuron and 81.6% for isoproturon were achieved under optimal conditions (adsorbent dosage: 2.0 g/L, contact time: 60 min, temperature: 25 °C) in agricultural runoff. Lower removal efficiencies of 76.5% and 73.4%, respectively, were observed in landfill leachate due to humic substances and competing ions. Although the biochar could be regenerated for 3–10 cycles, adsorption efficiency decreased after saturation, and improper disposal of spent biochar may cause secondary contamination. Future work should focus on improving regeneration methods, minimizing chemical inputs, and validating performance under industrial-scale conditions.

Acknowledgement

This research has been supported by the Ministry of Science, Technological Development and Innovation (Contract No. 451-03-137/2025-03/200156) and the Faculty of Technical Sciences, University of Novi Sad through project "Scientific and Artistic Research Work of Researchers in Teaching and Associate Positions at the Faculty of Technical Sciences, University of Novi Sad 2025" (No. 01-50/295)".

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Phosphates removal from wastewater by novel coagulant materials

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Phosphates (PO_4^{3-}) are a common aquatic pollutant that promotes eutrophication when present at elevated concentrations, leading to excessive algal growth, deterioration of water quality, and adverse impacts on aquatic ecosystems. Various treatment methods have been employed for phosphates removal from wastewater across a range of pH conditions, with coagulation being among the most widely applied. In this study, the composite coagulants were formulated using chitosan (CS) as a biopolymeric matrix in combination with tetravalent tin or divalent calcium. The phosphates removal efficiency of these composites (CS@Sn and CS@Ca) was evaluated in comparison with $SnCl_4$, chitosan (CS), and CaO. Batch experiments demonstrated that $SnCl_4$ achieved complete phosphates removal across all tested pH values, indicating a high degree of pH tolerance. The composite coagulant CS@Sn exhibited moderate removal efficiencies (35–43%), depending on pH, whereas chitosan alone showed negligible removal (2.4%) at pH 7, underscoring the importance of metal incorporation. In contrast, CaO achieved high phosphates removal (89%) at its optimal pH 7 but exhibited markedly reduced performance under acidic conditions (4%), reflecting strong pH sensitivity. The CS@Ca composite displayed limited effectiveness, with a maximum removal of 26% at pH 9, decreasing to 19% at pH 7 and 4.7% at pH 3. Overall, modification of chitosan enhanced phosphates removal compared to chitosan alone; however, the composite coagulants did not outperform the individual metal-based coagulants under the examined conditions, indicating that their effectiveness is strongly contaminant-dependent. Notably, $SnCl_4$ exhibited superior performance and pH tolerance, highlighting its suitability as an effective coagulant for phosphates removal.

Separate contributions of injection pressure and dissolved gas supersaturation on the efficiency of Dissolved Air Flotation process

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The degassing of a decompressing, supersaturated liquid flow constitutes the fundamental operating principle of Dissolved Air Flotation (DAF) wastewater treatment technique. DAF process is widely applied for the efficient separation of suspended solid particles from wastewater streams [1]. Degassing microbubbles attach to solid particles, promoting their flotation and efficient removal. The effect of decompression range on liquid degassing has been extensively studied in literature [2]. However decompression dictates both the liquid flow and the liquid supersaturation with dissolved air.

This work manages to disentangle the respective roles of injection pressure and dissolved gas concentration in controlling the characteristics of the resulting two-phase flow. To this end, synchronized macro-imaging and I-VED electrical impedance measurements with Multiplexer are employed, enabling spatially and temporally resolved quantification of bubble size distributions, gas volume fraction, and mixing evolution along the degassing column. Results show that, at a given supersaturation, the size of bubbles does not change with the injection pressure. The above indicates that number of degassing bubbles is strongly dependent on the injection pressure and the associated jet flow rate. Therefore, nucleation of degassing bubbles is attributed to cavitation. On the same manner, supersaturation increases the size of degassing bubbles as excess dissolved gas is distributed to the bubble population dictated by the injection pressure applied. Under the application of high injection pressure, supersaturation forces further bubble formation due to gas desorption.

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Vitivinicultural Waste Valorization: Biochar Modified with Distillation Residues for Enhanced Sorption Properties

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As the demand for clean water and efficient wastewater treatment (WT) grows, biochar (BC) has gained attention as a cost-effective material in sorption-based remediation technologies. In Greece, vitivinicultural and spirit production sector generates large volumes of grape residues and distillation by-products that remain underutilized, creating environmental burdens. Valorizing these wastes by converting grape waste into BC offers a circular, cost-effective route for WT [1]. In this study, BC was produced from grapevine prunings of Vitis vinifera L. (Muscat cultivar) via pyrolysis at 600 °C for 1 h (10 °C min^{-1}) under N_2 atmosphere. The produced BC (BC_GVP) was characterized in terms of specific surface area (SSA), crystallinity, surface functional groups, elemental composition, and surface charge. BC_GVP exhibited a SSA of 184 $m^2\ g^{-1}$ and total pore volume of 0.092 $cm^3\ g^{-1}$, while aromatic (C=C), carbonyl (C=O) and phenolic (O-H) groups were mainly identified on its surface. To enhance the sorption of pollutants (active pharmaceutical contaminants, dyes, heavy metals, petroleum etc.) from wastewater, a novel modification strategy employing spirit distillation fraction residues (heads and tails) from tsipouro (a traditional Greek spirit distilled from grape pomace) production is proposed. Heads are expected to increase SSA by enhancing pore accessibility, while tails can modify surface chemistry by increasing polarity and adding oxygen-containing functional groups [2]. Both modified BCs are expected to exhibit high sorption capacities for contaminants through pore filling, hydrogen bonding, π–π and electrostatic interactions [3]. This approach offers a "closing the loop" sustainable, low-cost activation route that integrates agricultural and distillation waste valorization for wastewater remediation.

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Enriched chitosan-based films with olive mill wastewater phenolics for olive oil stability improvement

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Olive mill wastewater (OMW) is one of the most challenging agro-industrial effluents due to its high organic load and phenolic content, which hinder conventional treatment processes. At the same time, OMW represents a valuable source of bioactive compounds with strong antioxidant activity, such as tyrosol, hydroxytyrosol. In this study, OMW, donated by an olive oil production unit (Eleourgia Prevezis S.A., Greece) was firstly characterized in terms of pH, total soluble solids and content in major phenolic compounds using HPLC. Filtration was also applied to reduce suspended solids. Then, phenolic compounds were extracted and the resulting phenolic-rich extract was incorporated into chitosan-based films to produce active packaging materials [1]. The prepared films were evaluated for their potential application in olive oil stabilization. Olive oil samples were stored in contact with the developed films and quality parameters and oxidative indices, including acidity, peroxide value, K232 and K268 values were examined periodically. The proposed process contributes to waste minimization, adds value to olive mill by-products, and supports the development of sustainable materials, in line with circular economy principles.

Acknowledgement

The study was conducted under the frame of "Agro Food Waste Recovery: new processing technologies for food Safety and Packaging (FoWRSaP)" project funded by European Union's Horizon 2020 PRIMA (Partnership for Research and Innovation in the Mediterranean Area) Section 2 Programme.

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Feasibility study on the application of nanofiltration membranes for treating wastewater from the steel and pulp and paper industries

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Nanofiltration (NF) is a well-established, cost-effective physical separation process that has advanced significantly over recent decades1. Although it is used in areas such as drinking water purification, water reuse, micropollutant removal, and food and pharmaceutical processing, its primary and most enduring application remains water softening. This study investigates the treatment of low-salinity wastewater streams from the steel and pulp and paper industries using NF membranes under different configurations and molecular weight cut-off (MWCO). The main objectives were to evaluate the performance of NF membranes while mitigating potential membrane fouling and/or scaling in the effort to separate monovalent and divalent ions in the wastewater streams. The physicochemical characteristics of the industrial wastewater streams indicated relatively low salinity (eC 1.9–2.5 mS/cm) and moderate organic content (11–150 mg/L COD). Lab-scale experimental units were used to evaluate the performance of both hollow fibre and flat sheet NF membranes. First, a series of batch mode cross-flow filtration experiments were conducted under different operating conditions (i.e. permeate flux, cross-flow velocity, water recovery) using two commercial hollow fibre NF membranes with different MWCO namely 400 and 800 Daltons. Results showed that NF membranes can achieve high rejection rates of divalent ions (82–89% Ca^{2+}, 82–87% Mg^{2+}, 85–95% SO_4^{2-}) under optimal conditions, even at high water recoveries of up to 87%, making NF suitable for efficient wastewater treatment. In subsequent tests, commercial flat sheet NF membranes were employed under dead-end mode, aiming to enhance solute recovery (high selectivity towards divalent ions) and minimise energy consumption. Bench-scale tests revealed that flat sheet NF membranes demonstrated high water recovery (70–74%) with limited fouling. The substantially high ion rejection (>80–90%) for divalent ions (Ca^{2+} and Mg^{2+}) suggests that NF can be effectively used to produce a stream rich in monovalent ions, which can be further valorised for the production of added-value products.

Acknowledgements:

The Authors acknowledges the financial support of the EU Horizon under the projects CORNERSTONE “Combined technologies for water, energy, and solute recovery from industrial process streams” (HORIZON-CL4-2023-TWIN-TRANSITION-01-40, Grant Agreement No. 101072449).

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Treatment of dairy industry wastewater employing in-series an anaerobic and an aerobic membrane bioreactor

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Dairy industry produces large volumes of high-strength wastewater that require efficient and sustainable treatment solutions. Due to stricter environmental regulations and the limitations of conventional energy-intensive processes, anaerobic membrane bioreactors (anMBRs) have emerged as promising alternatives; however, further treatment of the anMBR effluent is usually necessary for safe discharge1. In this study, a lab-scale system combining an anMBR in-series with an aerobic membrane bioreactor (aMBR) was studied over approx. 2.5 months for the treatment of dairy processing wastewater. During the start-up period, the anaerobic biomass was progressively acclimated to the dairy wastewater, enabling a gradual increase in the influent flow rate to 4 L/day while maintaining high treatment performance; organic matter removal reached 95% for TOC and 98% for COD. Simultaneously, biogas production reached approx. 1.0 L/day with methane content up to 70% v/v, confirming efficient anaerobic conversion. Following biomass adaptation, the system operated under steady continuous conditions at constant membrane flux, during which the anMBR consistently achieved TOC and COD removals of 91.4 to 99.6% and 95.1 to 99.9%, respectively. The subsequent treatment in the aMBR further improved effluent quality, resulting in overall removals exceeding 97.2% for TOC and 99.4% for COD in the vast majority of the measurements. The final permeate exhibited low residual concentrations of organics (~9.5 mg TOC/L and ~22 mg COD/L), suitable for discharge within permissible limits, while complete suspended solids removal (>99% turbidity reduction) was achieved by the ultrafiltration membrane. During stable operation, biogas production increased to 2.4 L/day, with methane and carbon dioxide contents of approximately 72% and 19% v/v, respectively; however, methane yield (0.03–0.18 Nm^3 CH_4/kg COD) remained well below the theoretical maximum (0.35 Nm^3 CH_4/kg COD), indicating the need for further optimization. Membrane fouling, indicated by increased transmembrane pressure (TMP), was observed in both membrane units, and was effectively controlled through chemical cleaning, demonstrating the robustness and high treatment efficiency of the integrated system.

Acknowledgements:

The Authors acknowledges the financial support of the EU under the project B-Resilient "Building the biomass resilience of food producing and processing SMEs through green and digitalized value chains" (SMP-COSME-2021-CLUSTER-01, Grant Agreement No. 101074621)

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Integrated crop protection approach regarding pesticide biodegradation study in the rhizosphere of wetland plant and its distribution in the artificial wetland substrate

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In recent decades, there has been a sharp increase in the pollution and degradation of surface water bodies by active substances of agricultural chemicals. The improper use of agrochemicals, and especially herbicides, has led to the contamination of surface waters with environmentally harmful organic xenobiotic substances, which originate from both point and non-point sources of pollution. In recent years, efforts have been made to remediate both water and soil resources from inorganic substances. However, few efforts have been recorded in the literature for the remediation of soil or water resources from organic xenobiotic pollutants and even fewer for active ingredients and metabolites of pesticides. Furthermore, in all techniques, the lack of an environmentally friendly philosophy that is also socially acceptable is evident. The use of artificial wetlands for the decontamination of waters contaminated with organic substances, such as the active substances of pesticides, can be considered as an alternative to the existing ones.

Phytoremediation deals with the cleanup of contaminated soil and water from organic or inorganic pollutants, using plants. The rhizosphere of Typha latifolia L. wetland plant favors the growth of specific microorganisms, which metabolize the xenobiotic substance of the herbicide and therefore indirectly the plant contributes to its degradation. The above mechanism of biodegradation in the rhizosphere region together with the ones of the absorption by the wetland sediment, phytoextraction and its metabolism within the plant tissues (Phytodegradation), constitute the set of the main phytoremediation mechanisms of the xenobiotic pesticides in this bioreactor.

Regarding the herbicide terbuthylazine due to its expected widespread use and the lack of data on its degradation in wetland ecosystems, it becomes necessary to study the possibility of artificial wetlands to be used as an alternative method for treating waters contaminated with the pesticide. Terbuthylazine is a selective, systemic herbicide commonly used in agriculture to control annual grasses and broadleaf weeds. In vineyards, terbuthylazine is typically used for weeding control under the vine rows and applied to established vines only (not young plantings).

For this purpose, eight surface-flow wetlands were constructed. Two types of substrates were used, sandyloam and mixture with zeolite. In addition, two levels of plant density were used, two and six rhizomes of Typha latifolia L. The randomized complete block design was used for the statistical evaluation. Were studied the following: a. the biodegradation in the rhizosphere, b. the distribution of the herbicide in the vertical cross-section of the substrate of the artificial wetlands.

The results revealed that the constructed wetlands remediate the herbicide efficiently. The herbicide TER showed higher concentrations in surface water samples compared to soil solution samples at a depth of 10cm from the surface of the artificial wetland substrate, near the rhizosphere area, while the herbicide metabolites showed the opposite behavior, highlighting the contribution of the bioreactor and specifically the rhizosphere to the degradation of the herbicide. Moreover, the distribution of the herbicide in the vertical section of the artificial wetland substrate at depths of 10, 20 and 30cm shows a gradual decrease as the depth increases, as absorption mechanism.

This study is sustainable and integrated plant protection approach with the aim of developing innovative, environmentally friendly solution for the protection and restoration of agricultural ecosystems.

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Monitoring, Control and Assessment of Urban Wastewater Management

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Cyprus has long faced a significant problem of water scarcity, which increases during the summer months due to limited precipitation, high evaporation rates, and increased water demand. The utilization and reuse of treated wastewater constitute a critical component of sustainable water resource management and the mitigation of water deficiency impacts. At the same time, monitoring the quality of urban wastewater represents an innovative and complementary approach for the detection and assessment of chemical risks at the population level, taking into account geographical and seasonal variations.

A total of 36 wastewater treatment plants (WWTPs) operate in Cyprus, of which 10 are large urban installations, while the remaining facilities serve rural areas, local communities, military premises, and hospital establishments. The quality of urban wastewater in Cyprus complies with the discharge permit limits of the Treatment Plants, in accordance with Council Directive 91/271/EEC, the national Water Pollution Control Law (Regulation 389/2015), and Regulation (EU) 2020/741 on minimum requirements for water reuse.

Concentrations of biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), and total suspended solids (TSS) are generally below the permissible limits (ML: 10, 70, and 10 mg/L, respectively), with occasional exceedances that are promptly addressed by the competent authorities, namely the Water Development Department and the Department of Environment. Total phosphorus (TP) and total nitrogen (TN) concentrations remain below the respective limits of 10 and 15 mg/L. Pesticides and Polycyclic Aromatic Hydrocarbons (PAHs) are detected at low concentrations (< LOQ), while heavy metals are found at levels significantly below the maximum permissible limits set by Regulation 379/2015.

Overall, all wastewater treatment plants demonstrate high treatment efficiency and low environmental risk.

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Production of NaOH and HCl from saline industrial wastewaters by bipolar electrodialysis

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In recent decades, the significant increase in saline wastewater production from industries such as food, oil & gas, pulp & paper, etc., has raised concerns within the scientific community about its safe management, directing interest toward developing innovative treatment methods aligned with zero-waste and circular economy strategies. Bipolar ElectroDialysis (BED) is a promising process for the valorization of saline wastewater into acid and basic solutions. Particularly, the anions and cations from saline wastewater are separated in different chambers using Anion and Cation Exchange Membranes (AEMs and CEMs), respectively. Bipolar Membranes (BPMs) are placed between them, where water dissociation occurs, forming H+ and OH- for the production of acid and basic solutions in the corresponding chambers. In this work, the performance of different commercial AEMs and CEMs was investigated in a commercial bench-scale BED unit for the production of NaOH and HCl through the treatment of real wastewater originating from the steel and pulp & paper industries. Initially, screening tests were conducted to select the optimal commercial AEM and CEM, focusing on the recovery of Cl- and Na+, Current Efficiency (CE, %) and Energy Consumption (EC, kWh/kgHCl/NaOH). In both cases, membranes from MEGA-RALEX Company provide the best results: 82% recovery of Na+ and 100% recovery of Cl- with 13.8 kWh/kgNaOH and 14.1 kWh/kgHCl. Subsequently, optimization was performed with synthetic NaCl solutions to identify the optimal operating conditions (applied voltage, recirculation flow, and volume ratio). Finally, experiments were carried out with the real wastewaters both in their raw form and after pretreatment with a nanofiltration process. In conclusion, the performance of the system with real wastewaters varied, with Cl- recoveries ranging from 20-94% and Na+ recoveries from 35-86%. This work was performed in the context of the CORNERSTONE project, which received funding from the European Union's Horizon Europe Research & Innovation Framework Program under Grant Agreement No 101138504.

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Filtration of Oil-in-Water Emulsions Using Ceramic Membranes

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The treatment of oily wastewater presents a significant environmental challenge due to the stability of oil-in-water (O/W) emulsions. Ceramic microfiltration membranes offer advantages such as high chemical resistance, mechanical stability, and the ability to operate under demanding conditions. In this study, the filtration of O/W emulsions were investigated using commercial ceramic membranes with different nominal pore diameters (0.2 μm and 0.8 μm) and various channel configurations (single-channel, seven-channel, and nineteen-channel), supplied by ATECH (Germany) and GUOCHU (China). Before emulsion experiments, tests with deionized water were conducted at constant cross-flow velocity (CFV) and varying transmembrane pressures (TMP) to determine the appropriate operating conditions for the O/W filtration experiments. The O/W emulsion was prepared by mixing bio-oil produced from the hydrothermal liquefaction of straw with glycerol and water at a concentration of 0.5% v/v, and stabilized by adding the anionic surfactant Sodium dodecyl sulfate (SDS). The total feed volume was 4 L. The experiments were conducted using a cross-flow filtration setup. Before the initiation of filtration, a sample of the initial feed was collected for Total Organic Carbon (TOC) determination and used as a reference value. During filtration, permeate samples were collected every 500 mL of produced volume. TOC analysis was then performed on the collected samples to evaluate the organic load removal of the different membranes and to identify the membrane with the highest performance. The membranes were compared based also on their clean water permeability (flux). The results allow evaluation of the effect of pore size on separation performance and investigation of membrane fouling phenomena. The experiments showed that the membrane achieving the best separation was the nineteen-channel membrane with a pore diameter of 0.8 μm. Over time, all membranes exhibited a decrease in flux due to fouling from the organic load.

Keywords: Ceramic Membranes, Oil-in-water emulsion, Microfiltration, Oily wastewater treatment

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Biochar–supported green nZVI for Nitrate Removal from Groundwater

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Nitrate contamination of groundwater represents a significant environmental and public health concern, particularly in agricultural and industrial regions [1, 2]. Nano zero-valent iron (nZVI) has attracted considerable attention as an effective reducing agent for the removal of inorganic contaminants from water [3, 4]; however, particle aggregation and rapid oxidation may limit its reactivity and practical application. In the present study, a composite material consisting of nano zero-valent iron supported on biochar derived from hazelnut biomass was synthesized and evaluated for nitrate removal from aqueous solutions. The nano zero-valent iron was prepared using an environmentally friendly synthesis method, employing green tea polyphenols as both reducing and capping agents. The biochar matrix acts as a stabilizing support for nZVI particles, improving their dispersion, surface reactivity, and resistance to oxidation. Batch experiments were conducted to investigate the influence of key operational parameters, such as solution pH and solid-to-liquid (S/L) ratio. In addition, the performance of the composite material was compared with that of pure biochar to assess the contribution of the supported nZVI. The results indicate that hazelnut biochar–supported nZVI exhibits enhanced nitrate removal efficiency compared to untreated biochar, highlighting the synergistic effect between the biochar support and the reactive iron nanoparticles. The proposed material represents a sustainable and low-cost approach for groundwater remediation while promoting the valorization of agricultural residues within a circular economy framework.

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ANALYTICAL CHEMISTRY OF EMERGING CONTAMINANTS

Groundwaters as environmental archive of PFAS contamination:

Vicenza Province (IT) as study case

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Groundwaters can act as long-lived environmental archives, recording the history of chemical contaminants releases in a catchment. Because recharge integrates signals over seasons to decades, aquifers preserve "memory" of episodic vs continued spills, changing industrial practices, and evolving consumer use. Unlike surface waters that respond rapidly to rainfall and dilution, groundwater often reflects cumulative loading and slow transport through the vadose zone. This makes it a powerful medium for reconstructing when, where, and how contaminants such as PFAS entered the environment. PFAS sources include industrial sites, landfills, wastewater treatment residuals, and diffuse urban inputs. Once released, PFAS exhibit high persistence and mobility, enabling migration along hydraulic gradients and the formation of elongated contamination plumes. As a result, PFAS "fingerprints" in groundwater can encode both the source type and the age of the contamination signal. High-resolution vertical sampling in wells can reveal legacy peaks from past uses or industrial discharges that no longer occur at the surface. Conversely, rising fractions of short-chain PFAS may indicate substitution trends following regulatory phase-outs of certain long-chain compounds. We will illustrate the above concepts by examining a large case study, in the Vicenza Province (Veneto, NE Italy), one of Europe's best-known PFAS groundwater hotspots: source max conc. ΣPFAS: 250-750 µg/l; plume longitudinal length: > 40 km; plume transversal width: 4-5 km; plume vertical depth: > 100 m; plume area (ΣPFAS> 0,5 ppb): 150 km^2; static water volume polluted : > 100 Mm^3; drinking water demand : 30-40 Mm^3/y . The contamination is linked mainly to decades of PFAS manufacturing at a chemical plant. The time-evolving "fingerprints" indicate transitions from legacy C8-era compounds to newer substitutes, a hallmark of regulatory-driven change. Overall, Vicenza Province case study exemplifies how groundwater archives can translate subsurface chemistry into actionable contamination histories. Reading this archive supports remediation prioritization, accountability, and protection of aquifers that supply communities and agriculture. Treating groundwater as an environmental archive therefore strengthens both PFAS science and decision-making in long-lived contamination crises.

Green(er) sample preparation methods for the monitoring of pesticides in environmental water samples

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In modern agricultural production, many different classes of synthetic and natural pesticides are widely used to maximize harvest yields and simultaneously control insects, fungi, bacteria, weeds, and other pests. These compounds exhibit high potential for the contamination of aquatic ecosystems mainly surface and groundwater. Due to their association with various health risks, their monitoring in water samples is critical. During recent years, there is a continuous effort from the scientific community to reduce the environmental impact of analytical chemistry. Undoubtedly, sample preparation is among the most polluting steps of chemical analysis. To make this step "as green as possible" a plethora of microextraction and miniaturized extraction techniques have been developed to replace traditional sample preparation techniques. Typical examples of novel sample preparation include dispersive solid-phase extraction, magnetic solid-phase extraction, fabric phase sorptive extraction, and capsule phase microextraction. These techniques reduce the consumption of organic solvents and the amount of the generated waste. The combination of these sample preparation approaches with gas and liquid chromatographic techniques can be efficiently employed for the monitoring of multi-class pesticides including organochlorines, organophosphorus, carbamates, pyrethroids, phenyl urea, and benzoyl urea pesticides in environmental water samples.

Development and Validation of a UHPLC-MS/MS Method for the Determination of EU Watch List Emerging Contaminants in Wastewater and Sludge

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Emerging contaminants pose a risk to the environment as a result of their persistence, bioactive nature and potential pollutant activity in, or via, the aquatic environment1. The aim of this study was to develop an original and reliable method for the quali-quantitative analysis of 36 emerging pollutants, including 29 compounds from the EU watchlist (Directive 2025/439), in wastewaters and sludge by UHPLC-MS/MS, exploiting direct injection for wastewater samples and solid-phase extraction (SPE) prior to analysis for sludge samples. Target compounds included pharmaceuticals, cosmetic ingredients, fungicides and industrial chemicals. Analytical conditions for all 36 analytes were optimised and validated, allowing their determination in a single 14-minute chromatographic run. Calibration curves in the 5-600 ng/L range showed R2 > 0.9900 for all analytes. For some target compounds (e.g., Parsol 340, itraconazole, etoxazole, Parsol 1789 and guanylurea), matrix effect causing ion suppression was observed; it was possible to mitigate it by properly diluting the matrix without losing analytical integrity. Method precision, expressed as RSD at three concentration levels (5, 25 and 100 ng/L), was always below 13%. Several compounds in the EU watchlist require very low limits of quantitation (LOQ), in particular avermectin B1a and B1b (LOQ = 1 ng/L), etoxazole (0.4 ng/L) and fipronil (0.77 ng/L). Accordingly, an original SPE protocol was developed and optimised to enable quantitation at the required low ng/L levels, and it was successfully applied to the determination of selected analytes in sludge samples.

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Development of an SPE-LC-MS/MS analytical method for the simultaneous determination of TFA and Sum of PFAs.

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Per- and polyfluoroalkyl substances (PFAS) have emerged as a critical global environmental issue due to their extreme persistence and potential adverse effects on human health and ecosystems. While traditional monitoring has focused on long-chain PFAS, recent scientific attention has shifted toward ultrashort-chain (USC) PFAS (carbon chain length < C4), such as Trifluoroacetic acid (TFA). [1,2]

TFA is often the most abundant USC compound in environmental waters, partly due to the atmospheric breakdown of specific refrigerants. However, analyzing TFA alongside legacy PFAS presents significant challenges because its high polarity and small size lead to poor retention in traditional reversed-phase liquid chromatography (RPLC). [3]

This study aims to provide a comprehensive assessment of PFAS contamination in the water supply of Thessaloniki, Greece, by utilizing a validated methodology for the simultaneous determination of TFA and the 20 PFAS analogues included in the current European Drinking Water Directive (DWD).

Multiple chromatographic columns (C18, HILIC, and MMI) were evaluated to ensure sufficient retention of TFA and PFA analogues, and different mobile phase compositions and gradient programs were optimized to improve peak shape—particularly for TFA—and achieve optimal elution behavior.

Based on these evaluations, the optimal combination of the aforementioned parameters was established and implemented for analytical method validation.

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Chemical Fingerprinting of Urban Water Runoff: An Integrated HRMS Non-Target Workflow and Machine Learning Framework for Source Tracking

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Urban water runoff transports diverse emerging pollutants into surface waters and waste water systems, but complete chemical profiling remains challenging due to contaminant complexity and analytical constraints. Herein, we present a framework combining high-resolution mass spectrometry (HRMS) non-target screening with machine learning to characterize and trace organic micropollutants in Thessaloniki's urban water runoff. Runoff samples were collected from four points (industrial-residential, commercial, residential, and port areas) during precipitation events. Our custom analytical pipeline integrating experimental and in-silico predicted spectral libraries achieved confident assignments for 175 compounds: industrial chemicals, PFAS, personal care products, antimicrobials, and biogenic substances. For source discrimination, we systematically compared 16 modeling configurations varying annotation confidence, algorithms, and regularization strategies. Elastic Net-regularized Logistic Regression yielded optimal performance (62.5% balanced accuracy), confirming that high-quality annotations prevent overfitting in small-sample scenarios. SHAP feature attribution revealed 29 key tracers differentiating emission sources: industrial sites displayed fluorinated compounds (PFOA, PFNA, PFDA), whereas port and commercial zones exhibited lifestyle indicators (illicit drugs, surfactants). Time-series clustering showed industrial pollutants undergo early-event wash off while subsurface metabolites mobilize later. Our findings demonstrate how linking robust chemical identification with machine learning converts HRMS data into actionable source intelligence, supporting targeted regulatory actions and evidence-based urban water management.

The research work was supported by the Hellenic Foundation for Research and Innovation (HFRI) under the 4th Call for HFRI PhD Fellowships (Fellowship Number: 11177).

Incorporating automated systems for the determination of PAHs in environmental waters. The green and blue analytical perspectives

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Automated systems in sample preparation have become a key driver of modern analytical methodology, offering substantial advantages in terms of reliability, efficiency, and sustainability. By integrating extraction, clean-up, and preconcentration steps into controlled on-line or at-line workflows, automation minimizes human intervention, thereby reducing operator-related variability and improving method precision and reproducibility. Automated platforms also enable better control of critical parameters (flow rates, volumes, timing), leading to enhanced extraction efficiency and consistent analytical performance.

Polycyclic aromatic hydrocarbons (PAHs) are priority environmental pollutants due to their persistence, bioaccumulation potential, and carcinogenicity, necessitating sensitive and reliable monitoring in aquatic systems. In this context, an automated analytical methodology was developed and validated for the determination of 16 PAHs in environmental waters, integrating on-line sample preparation with GC–MS/MS detection. The approach is based on a novel flow-injection–solid-phase extraction (FI–SPE) system enabling automatic on-line preconcentration, using poly-tetrafluoroethylene (PTFE) turnings packed into a miniaturized preconcentration column as an alternative sorbent material. Critical parameters affecting extraction efficiency—sample loading flow rate, sample volume, elution solvent type and volume, and sample ionic strength (NaCl addition)—were systematically optimized. Under optimum conditions, the method demonstrated excellent linearity ($R^2 > 0.991$), low limits of detection (1.5–7.6 ng L^{-1}) and quantification (5.0–25.0 ng L^{-1}), and enrichment factors between 25.7 and 60.5. Precision was satisfactory, with RSD values not exceeding 10.8%, while relative recoveries ranged from 83.8–98.8% (repeatability) and 87.4–97.9% (reproducibility).

Beyond analytical performance, the proposed platform aligns with green analytical chemistry (GAC) principles by minimizing solvent consumption, reducing manual handling, and limiting waste generation through automation and miniaturization. Simultaneously, it addresses blue analytical chemistry (BAC) concepts by enhancing method safety, operational simplicity, and resource efficiency, while supporting high sample throughput for routine environmental monitoring.

Taking decisions on sustainability based on measurements: Interpretation of uncertainty and associated risk

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Environmental risk management sits at the intersection of environmental governance, industrial processes, economic activity, and social well-being. Decisions in this area increasingly rely on evidence-often large datasets generated through measurements-combined with expert judgement and structured reviews of real-world data.

Measurements are used to describe the current state of the environment, identify trends in contaminants, and quantify material flows and pollutant emissions. Such data are typically produced by specialized accredited laboratories. Crucially, every measurement result is accompanied by measurement uncertainty, and established decision rules exist for how to use a result together with its uncertainty—particularly when results fall close to a decision limit raised by regulation, specifications or standards.

However, the way uncertainty should be interpreted and incorporated is not purely technical. It depends on associated: the broader system impacts of an outcome, the consequences of different decisions, and the purpose of the decision itself—especially in sustainability-related contexts where trade-offs can span environmental, economic, and societal dimensions. Multiple approaches may be appropriate, but selecting the right one requires aligning measurement-based evidence with risk-based decision-making.

A recurring challenge is the gap between laboratory scientists—who can rigorously justify risk-based approaches—and decision-makers, who often come from non-technical backgrounds yet must understand unfamiliar concepts under real policy and operational pressure. This talk argues that there is a shared ground between these communities, and that strengthening knowledge exchange is essential: decision-makers need clear, usable information about measurement results and uncertainty, while laboratories need context about decision objectives, impacts, and associated risks. Building this mutual understanding supports more robust sustainability decisions and better environmental governance.

Determination of per- and polyfluoroalkyl substances (PFAS) in aqueous matrices using UHPLC Q-TOF

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The primary aim of this study is to detect perfluoroalkyl and polyfluoroalkyl substances (PFAS) due to their lately widespread and concerning environmental contamination. These long-chain, consistent chemical compounds prompted regulatory measures and have initiated the need to discover as more techniques for their detecting and monitoring. In this work, applied method combines the technique of Ultra High Performance Liquid Chromatography (UHPLC), coupled with mass spectrometry (MS), for the identification and quantification of perfluorinated alkylated substances (PFAS) in drinking water. From many available mass detectors, the present methodology uses the Q-TOF (Quadrupole Time Of Flight) with Dual Agilent Jet Stream Electrospray Ionization (Dual AJS ESI) ion source. Solid Phase Extraction (SPE) is applied to extract the PFAS in a test matrix. Moreover, method investigates a specific group of 20 per- and polyfluoroalkyl substances that the European Union requires member states to monitor in drinking water, and this group includes 10 compounds based on carboxylic (PFCAs) and 10 compounds based on sulfonic chemical group (PFSAs). Consequently, method efficiency showed acceptable outcome regarding to average recovery (70-130%), detection/quantification limits (the most compounds reached limit of quantification 0.002 µg/L) and linearity (R2>0,98).

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Determination of Haloacetic acids in drinking water by SPE–UPLC–MS/MS using manual and automated sample preparation

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Haloacetic acids (HAAs) are among the two major disinfection by-products (DBPs) in drinking water and are characterized by high polarity and very low pKa values, rendering their detection and quantification at low concentrations challenging 1. HAAs have been associated with adverse health effects, including increased risks of bladder cancer and reproductive toxicity, making monitoring essential 2.

In this study, a rapid, sensitive, robust, and reliable analytical method was developed and validated for the determination of nine HAAs in drinking water samples from Thessaloniki area. The method is based on liquid chromatography–tandem mass spectrometry (LC–MS/MS) following solid-phase extraction (SPE). Two SPE procedures were evaluated: manual (MSPE) and automated (ASPE), both employing the same extraction protocol. The accuracy of the two approaches was experimentally assessed, and statistical comparison using a t-test demonstrated equivalent performance, confirming the method's robustness and flexibility.

The validated method exhibited satisfactory analytical performance, with limits of quantification from 1.85 to 4.88 μg L^{-1}. Relative recoveries ranged between 75% and 110%, while repeatability (RSDr%) and reproducibility (RSDR%) were <13% and <17%, respectively.

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Microfluidic devices for fast detection of viruses and bacteria

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Early detection of pathogens, in both clinical and environmental settings, is key for a fast and effective response. Current detection methods mainly rely on microbiological techniques that require 24-48 hours for reliable results. For this reason, our research group has been developing fast and affordable point-of-care testing for early identification of microbial and viral contaminations. We developed miniaturized devices for speeding up and simplifying identification of bacteria and viruses in human specimens, taking inspiration from conventional microbiological methods[1,2] and immunoassays[3]. These microfluidic tests require minimal equipment and enable analytical methods outside centralized laboratories and hospitals. In addition, we have broadened our range of testing to DNA extraction and detection, achieving promising results in multiple sample types, including blood and river water[4]. Ongoing work is exploring application to a wider range of analytes in compact microfluidic designs for monitoring bathing waters and wastewater epidemiology.

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Source-Control Circular Mitigation of Gadolinium Pollution: Direct Magnetic Nanomaterial Removal from Urine after MRI Examinations

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Gadolinium-based contrast agents (GBCAs) used in magnetic resonance imaging (MRI) are essential for diagnosis but are not metabolised and are rapidly excreted in urine, making them a major source of gadolinium in hospital wastewater. Because conventional treatment processes cannot remove these stable compounds, gadolinium is continuously released into aquatic environments, raising long-term environmental and ecotoxicological concerns.1 This study proposes a circular and resilient source-control strategy in which Gd removal is performed directly at the point of origin, prior to dilution in hospital effluents. The approach relies on the collection of urine from patients undergoing MRI examinations in dedicated facilities, followed by treatment with manganese ferrite ($MnFe_2O_4$) magnetic nanoparticles as a low-cost and easily recoverable sorbent. Batch sorption experiments were conducted using urine as the target matrix, reflecting realistic clinical discharge conditions. The influence of nanoparticle dosage (20–180 mg/L), initial Gd concentration (1–5 μmol/L), and salinity (0–30 g/L) was evaluated at near-neutral pH. Response surface methodology (RSM) was applied to optimise removal efficiency. Under optimal conditions, $MnFe_2O_4$ nanoparticles achieved Gd removal efficiencies exceeding 90% within one hour, with performance remaining stable across a wide salinity range. The magnetic properties of $MnFe_2O_4$ enable rapid separation and reuse, promoting circularity and reducing waste, while source-level Gd removal lowers the environmental footprint of diagnostic imaging. This work demonstrates a practical, scalable pathway to enhance the resilience and sustainability of healthcare-related wastewater management.

Acknowledgements

This work was funded by Portuguese national funds (FCT/MCTES) through CICECO-Aveiro Institute of Materials (UIDB/50011/2020 & UIDP/50011/2020) and REQUIMTE (UID/50006 – Associated Laboratory for Green Chemistry), and by COMPETE2030-FEDER-00847800.

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Toxicity Mixtures:
A Paradigm Shift in the 2025 Update of the Water Framework Directive

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Environmental risks of chemicals in aquatic systems have traditionally been assessed on a substance-by-substance basis, largely neglecting the combined effects of chemical mixtures. However, real-world exposures typically involve complex multicomponent "cocktails," and ignoring mixture toxicity may lead to substantial underestimation of environmental risks. Recognizing this limitation, the 2025 update of the Water Framework Directive (WFD) introduces a shift from single-substance assessment toward consideration of mixture effects.

This contribution outlines a tiered framework for environmental mixture toxicity assessment that reflects emerging good practice and supports the modified compliance check foreseen under the Water Framework Directive. The framework builds on the two well-established mixture toxicity concepts, Concentration Addition (CA) and Independent Action (IA). CA is applied as a precautionary first-tier approach, independent of the modes of action of the mixture components, providing conservative and protective risk estimates. The next tier evaluation incorporates mode-of-action information to refine risk characterization and improve regulatory relevance.

To support compliance with the revised WFD, the toxicity unit approach is applied to pesticide mixtures, integrating substance-specific environmental quality standards with mode-of-action classifications derived from IRAC and HRAC schemes. Selected examples demonstrate how this combined framework enables more realistic and reliable assessment of mixture toxicity for pesticides considered as priority pollutants under the WFD.

Acknowledgment:

The authors acknowledge the financial support by the project BG-RRP-2.017-0038-C01 "Web-based platform for in silico assessment of toxic effects of chemicals on human health and the environment" funded by the European Union through the NextGenerationEU instrument under the Recovery and Resilience Facility in implementation of investment C2I2: "Enhancing the innovation capacity of the Bulgarian Academy of Sciences in the field of green and digital technologies".

Integrating QSAR Models into a Web-based Platform for Aquatic Toxicity Prediction

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The European chemicals regulation REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) aims to safeguard human health and the environment from chemical hazards. Traditional laboratory animal testing raises ethical concerns, it is costly and time-consuming. As a result, REACH encourages the use of alternative approaches, including in vitro and in silico ones. In silico approaches offer fast and cost-effective solutions for chemical hazard assessment. Developing freely accessible in silico models and integrating them into user-friendly software or web-based platforms is critical for toxicology researchers, regulators, and industry, facilitating optimized risk assessment and prioritization of substances for further testing.

To address this need, we are developing an integrated, web-based platform providing free access to a broad spectrum of in silico models relevant for regulatory toxicology. This work focuses on the integration of QSAR (quantitative structure-activity relationships) models developed by our team, covering acute toxicity for various aquatic organisms, including crustaceans (Daphnia magna). All models comply with the QMRF (QSAR Model Reporting Format) and are incorporated into a unified database. The models will be made publicly available via comutox.bas.bg, providing a valuable resource for researchers and regulators working to reduce animal testing while ensuring chemical safety.

Acknowledgment:

The authors acknowledge the financial support by the project BG-RRP-2.017-0038-C01 "Web-based platform for in silico assessment of toxic effects of chemicals on human health and the environment" funded by the European Union through the NextGenerationEU instrument under the Recovery and Resilience Facility in implementation of investment C2I2: "Enhancing the innovation capacity of the Bulgarian Academy of Sciences in the field of green and digital technologies".

Electrochemical Lead Detection in Water Using Graphene–Nafion–Ionic Liquid Modified Carbon Electrodes

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Heavy metal contamination in water, particularly toxic Pb(II), Cd(II), and Zn(II) at concentrations exceeding permissible limits, poses severe public health risks including cardiovascular disease and neurotoxicity [1]. While methods like ICP-MS and AAS offer high precision, their high cost and lab requirements necessitate cost-effective alternatives. Electrochemical methods using modified carbon electrodes meet these needs through enhanced sensitivity and stability [2].

This study investigates the detection of Pb(II) using chronoamperometric deposition followed by differential pulse voltammetry (DPV) stripping analysis on a glassy carbon electrode modified with a graphene/Nafion/ionic-liquid composite (G/N/IL/GCE). Optimal deposition was achieved at -1.0 V for 240 s (tuned from 120-300 s time, -0.8 to -1.4 V potential ranges). Sharp Pb stripping peaks appear at -0.7 V and using 100 ng/mL Bi(III) formed an in-situ bismuth film (peak at -0.3 V) that improved low-concentration response. Calibration for Pb(II) (5–50 ng/mL) showed good linearity ($R^2 = 0.9716$) with a LOQ of 5 ng/mL, and reproducibility at 50 ng/mL (n = 5) gave RSD = 7.02%. Multi-metal measurements (Pb, Cd, Zn; 5–50 ng/mL) produced resolved peaks at −1.1 V (Zn), −0.9 V (Cd), and −0.7 V (Pb), indicating potential for simultaneous multi-metal screening.

The G/N/IL/GCE platform delivers sensitive, practical trace Pb(II) detection with multi- metal capability—ideal for decentralized monitoring in sustainable water management.

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Development of a fabric phase sorptive extraction method for the monitoring of monomers released from dental resin composites in dental wastewater analyzed by HPLC-DAD

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A novel fabric phase sorptive extraction method (FPSE) was developed for the detection of monomers released during dental restorative procedures, which are subsequently discharged into the environment through dental unit drainage systems. The presence of Bisphenol-A (BPA), Triethylene glycol dimethacrylate (TEGDMA), Urethane dimethacrylate (UDMA) and Bisphenol A-glycidyl methacrylate (Bis-GMA), released from dental resin composites in dental wastewater was monitored using high pressure liquid chromatography coupled to diode array analysis (HPLC-DAD). FPSE was optimized with respect to the following significant parameters: (a) membrane type and size, (b) sample volume, (c) extraction time, (d) stirring rate during extraction, (e) elution time, (f) agitation during elution, (g) elution solvent, and (h) ionic strength. For HPLC-DAD analysis, the mobile phase constituted of acetonitrile-water and a gradient elution program was followed. The detection was carried out at 220 nm. The method was validated in terms of linearity, sensitivity, selectivity, accuracy, and precision, showing satisfactory results. The limits of detection (LOD) and quantification (LOQ) were equal to 0.015 ng/μL and 0.05 ng/μL, respectively, for BPA, TEGDMA, and Bis-GMA, and 0.03 ng/μL and 0.1 ng/μL, respectively, for UDMA. The method demonstrated satisfactory precision, with relative standard deviation (RSD) values lower than 7.7 % for intra-day and lower than 9.5 % for inter-day studies. Recoveries ranged from 93.9% to 100.8% (intra-day) and from 92.0% to 101.7% (inter-day) for all target analytes. The developed method was successfully applied to a real dental wastewater sample, with direct immersion of the FPSE medium into the sample after simple centrifugation and filtration.

Exploring the Potential of Biochar-based Fabric Phase Sorptive Extraction for the Extraction of Emerging Contaminants

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Emerging contaminants are frequently detected in the environmental waters but are poorly regulated and have the potential to cause environmental and aquatic toxicities. Classical extraction techniques have been employed for these contaminants but these techniques involve many steps and use large volume of toxic organic solvents. Fabric phase sorptive extraction (FPSE) is a promising extraction technique because it only involves two steps, uses low volume of organic solvents, and achieves faster extraction equilibrium due to increased sorbent loading and contact surface area. In FPSE, the sorbent is made from a fabric that is thinly coated with a sol-gel polymer. Biochar is an adsorbent material with many surface functional groups capable of interacting with the target contaminants. In this study, we explored the use of biochar as coating for microfiber glass. Biochars were obtained by pyrolyzing lemon peels (LP) and sewage sludge (SS), which were eventually characterized by FTIR and SEM. The biochar-based FPSE sorbents were prepared by coating a pretreated microfiber glass with sol-gel consisting of the biochar and precursor (trimethoxymethysilane). In the end, two biochar-based FPSE sorbents were obtained: LP-biochar and SS-biochar which were characterized by FTIR. The efficiencies of the sorbents were studied for the simultaneous extraction of caffeine (CAF) and carbamazepine (CBZ), and antidiabetic drugs (pioglitazone, dapagliflozin, glimepiride, metformin, gliclazide, and repaglinide). Using a previously optimized extraction conditions of 1 mL sample of 1 mg/L of contaminants, extraction for 45 min with vortexing, and elution with 100 μL of acetonitrile for 10 min, the adsorption efficiencies and absolute extraction recoveries for the contaminants were determined. Using LP-biochar-based sorbent, CAF and CBZ had 17.7% and 27.9% adsorption efficiencies, and 9.36% and 20.1% absolute extraction recoveries. For the SS-biochar-based sorbent, CAF and CBZ had 23.4% and 39.3% adsorption efficiencies, and 4.14% and 22.2% absolute extraction recoveries. For the extraction of antidiabetic drugs, LP-biochar-based sorbent had 29.4 – 97.3% adsorption efficiencies and 12.8 – 44.0% absolute extraction recoveries. On the other hand, SS-biochar-based sorbent had 11.7 – 100% adsorption efficiencies and 36.6 – 49.8% absolute extraction recoveries. In general, the SS-biochar performed better than LP-biochar due to more exposed surface functional groups. This study confirms the potential of biochar-based sorbent for the extraction of emerging contaminants.

LC-HRMS-based environmental monitoring of emerging contaminants in river water using suspect and non-target analysis

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Monitoring emerging contaminants in river water is crucial for understanding their environmental distribution, persistence, and potential ecological risks. High-resolution mass spectrometry (HRMS)-based suspect and non-target screening approaches provide advanced tools for the comprehensive monitoring of both known and previously unmonitored emerging contaminants (ECs) in aquatic matrices. In this study, river water samples were collected from the Aliakmonas and Pineios rivers were extracted using an optimized SPE workflow and subsequently analyzed in an LC-Orbitrap-HRMS system. Suspect screening utilized an extended suspect list (>2500 compounds and TPs) compiled from literature and laboratory data. Complementary non-target workflows were implemented using Compound Discoverer software, including automated feature extraction, elemental composition prediction, spectral library searching via mzCloud, and in silico fragmentation-assisted annotation. Suspect screening revealed the presence of more than 50 compounds in river water samples, whereas non-target workflows contributed to the identification of more than 10 additional compounds. Detected substances belonged to multiple chemical classes, including pharmaceuticals (e.g., caffeine, valsartan, venlafaxine, irbesartan, and trimethoprim), pesticides (e.g., tebuconazole, boscalid, and carbaryl), and consumer-use chemicals such as DEET. In addition, several transformation products were tentatively annotated. Occurrence patterns showed elevated detection frequencies of caffeine, DEET, tebuconazole, and valsartan, indicating their persistent presence in surface waters. These results highlight the capability of LC-Orbitrap-HRMS, in combination with suspect and non-target screening approaches, to provide comprehensive insight into the chemical composition and occurrence patterns of emerging contaminants in river systems.

The research project was supported by European Commission under the HORIZON-WIDERA- TWINNING BOTTOM-UP within the framework of the SPECTRA project (Grant No 101158453).

Development of a molecularly imprinted polymer-based fabric phase sorptive extraction (MIP-FPSE) for the highly selective isolation of BPA from environmental waters prior to HPLC-DAD analysis

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Bisphenol A (BPA) is one of the most widely produced and commonly encountered endocrine-disrupting chemicals found in everyday consumer materials. In the present work, BPA was determined in environmental water samples using a Fabric Phase Sorptive Extraction (FPSE) membrane modified with molecularly imprinted polymers (MIPs), combined with high-performance liquid chromatography equipped with a diode array detector (HPLC–DAD). The MIP-FPSE-HPLC-DAD procedure was thoroughly optimized through systematic investigation of factors affecting analytical efficiency, such as sample pH, magnetic stirring time and speed ratio, extraction solvent type and volume, vortex-assisted desorption time, and salt addition.

The developed MIP-FPSE membranes can be reused for up to ten extraction cycles. An imprinting factor (IF) of 6.78 ± 0.19 (n = 3) was obtained, demonstrating strong selectivity and affinity of the imprinted sites for BPA. Method validation included evaluation of linearity, sensitivity, accuracy, and precision. The method showed excellent linear behavior ($R^2 = 0.9990$) within the studied concentration range. Extraction recoveries ranged between 92.7% and 97.1%, while relative standard deviation (RSD) values were below 6.8%, indicating good repeatability and precision. The limits of detection (LOD) and quantification (LOQ) were estimated at 0.008 mg/L and 0.025 mg/L, respectively, highlighting the method's suitability for detecting BPA in environmental waters at trace levels.

Determination of perfluoroalkyl carboxylic acids in wastewater samples using fabric phase sorptive extraction and benzyl bromide derivatization

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PFAS are synthetic fluorinated compounds that are used in industrial applications because of their high stability and resistance to degradation. Because of their environmental persistence and bioaccumulation, PFAS are commonly detected in wastewater, biosolids, and composts. Wastewater treatment plants (WWTPs) are important monitoring points for PFAS since they collect water from landfill leachates, stormwater, domestic, agricultural and industrial effluents [1]. Due to the associated environmental and health concerns, the analysis of wastewater samples from WWTPs is quite important. The aim of this study was to develop an analytical method based on microextraction and derivatization to determine PFAS, specifically perfluoroalkyl carboxylic acids (PFCAs), in wastewater samples using gas chromatography (GC). To minimize matrix effects and preconcentrate the analytes, fabric phase sorptive extraction (FPSE) was used as an efficient and solvent-minimizing extraction technique. The main extraction, adsorption and elution parameters were optimized using a one-variable-at-a-time (OVAT) approach. PFCAs are ionic, stable and therefore nonvolatile, which make them unsuitable for direct analysis by GC. Therefore, derivatization prior to GC analysis is required to convert the polar carboxylic acid into a neutral and more volatile derivative. Different reagents were tested including N,O-bis(trimethylsilyl)trifluoroacetamide (BSTFA), trimethyl sulfonium hydroxide (TMSH), benzyl bromide, isobutyl chloroformate (IBCF), trimethyl silyl diazomethane (TMSD), tetraalkylammonium (TAA) salts, trimethyl orthoformate, triethyl orthoformate. The reaction conditions were comprehensively optimized for the selective and sensitive determination of PFCAs in wastewater samples.

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Determination of 16 fluorobenzoic acids in reservoir water samples as tracers for petrochemical exploration: Combination of derivatization and microextraction with GC-MS

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In this study, a fabric phase sorptive extraction (FPSE) protocol combined with gas chromatography was developed to monitor the concentrations of 16 fluorobenzoic acids (FBAs) in water samples. FBAs are widely used as tracers in petrochemical exploration due to their stability and relative ease of detection and allow to trace the hydrogeological situation underground, which is both relevant to efficiently produce oil, as well as to minimize environmental harm due to oil production [1]. Because FBAs typically occur at trace levels in produced water, a preconcentration step is essential. For this purpose, FPSE, which uses sol-gel coated fabric substrates for analyte extraction, was employed as a green alternative to conventional sample preparation techniques commonly used in environmental analysis [2]. For the derivatization of the FBAs, trimethyl sulfonium hydroxide was used as a methylating agent at 75°C for 1 h. A gas chromatography-mass spectrometry method was developed and validated in terms of selectivity, linearity, sensitivity, accuracy, and precision for the quantification of FBAs. The limits of quantification were 2.5-5.0 ng mL-1, and the limits of detection were 0.76-1.52 ng mL-1. The relative standard deviation (%RSD) was less than 10% and the relative recovery (%) ranged from 81.2-118.5% in all cases, showing good precision and accuracy, respectively. This validated method was practical and sustainable, as proved by using appropriate metric tools, and was successfully used to monitor the concentrations of FBAs in reservoir water samples following their used as tracers.

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ProPla

Turning waterborne plastic into the building blocks of life: the ProPla project

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The accumulation of polyethylene terephthalate (PET) in aquatic and terrestrial environments represents a critical sustainability challenge. Here we describe a biotechnological strategy to valorize post-consumer micro- and nanoPET, as well as the one recovered from freshwater systems or domestic washing machines, into high-value biomolecules. An engineered leaf-branch compost cutinase (S101N/F243T-ΔLCC) efficiently depolymerizes PET into terephthalic acid (TPA) and ethylene glycol at mild temperature (37 °C), enabling direct integration with a downstream biocatalytic system for their valorisation (1). TPA was converted by an engineered *Escherichia coli* strain into 2-pyrone-4,6-dicarboxylic acid and subsequently into pyruvate using recombinant enzymes to avoid metabolic loss. Pyruvate was finally aminated to produce enantiopure D- or L-alanine and related biomolecules. This twelve-enzyme biosynthetic pathway, distributed across modular whole-cell and cell-free systems, assembled from four microorganisms, converted untreated post-consumer PET into alanine at gram-per-litre titres with an overall yield of ~0.3 g g^{-1} PET, establishing a circular and sustainable route for transforming plastic waste into biological building blocks (2). By enabling access to central metabolic intermediates, this platform opens the door to the sustainable synthesis of a broad range of molecules of industrial and biomedical relevance.

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Improving insect-mediated bioconversion of polyethylene terephthalate by stable gut colonization of recombinant Escherichia coli

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Insect-mediated bioconversion allows the valorisation of organic wastes from the agrifood chain, as obtained high-value insect biomass can serve as important source for animal feed production. The larvae of the Black Soldier Fly (BSFL) are extensively studied for a wide range of biotechnological applications to improve the circularity of several product chains. Recently, BSFL have also attracted considerable interest for the biodegradation of plastics polymers thanks to the remarkable plasticity of their gut microbiome[1,2].

Within the framework of the ProPla project funded by Cariplo Foundation, BSFL were used to develop a sustainable and circular bioconversion process for polyethylene terephthalate (PET) plastic. The aim of our research unit was to achieve stable colonization of the larval gut by a bacterial strain (i.e., *Escherichia coli* which is not normally present in BSFL gut microbiota) expressing enzymatic pathways to bioconvert PET into amino acids. We developed a protocol to orally administer wild-type *E. coli* to BSFL through the rearing substrate and to monitor the colonization along the gut over time. We demonstrated that the composition of the rearing substrate is the most critical factor for achieving stable colonization by metabolically active *E. coli*, whereas polymers commonly used to embed and protect bacteria (e.g., alginate and chitosan) did not improve colonization. In addition, RT-qPCR analyses confirmed that the bacteria colonizing the gut were metabolically active. Overall, this work provides a platform of knowledge for understanding the mechanisms underlying *E. coli* colonisation dynamics in the BSFL gut. Research on colonization by a recombinant bacteria capable of degrading PET and/or bioconverting its degradation products into amino acids is currently ongoing.

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Proteins from (Micro)Plastics: a Circular Bioeconomy Perspective

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The unsustainable use and disposal of plastics is causing persistent and widespread environmental contamination. In particular, the pervasiveness of microplastics (MPs) in wastewater has become a major environmental issue in aquatic ecosystems and may cause adverse health effects for humans and other living organisms.

In this scenario, the Protein from Plastic (ProPla) project, funded by Fondazione Cariplo, aims at developing an innovative biotechnological application to recover PET microplastics (microPET) from wastewater and exploit the power of protein engineering and system biology approaches to generate a novel bacterial strain able to convert microPET into amino acids, that can be used in many industries (food, cosmetics, etc.) in a circular bioeconomy perspective.

This paper presents the socio-economic framework of the ProPla project, which includes a patent landscape analysis (PLA) and a socio-economic assessment, aiming to highlight the system of values and the economic opportunities embodied in the process.

The PLA had a crucial importance to map the main technological trends related to the ProPla process, highlighting opportunities with significant potential economic return for the isolation of MPs from water, their characterization and the set-up of a novel *E. coli* strain for the conversion of PET into amino acids.

The socio-economic assessment aimed at underlining the multiple direct and indirect values arising from the project outcomes and products. The issue of the economic feasibility of microPET conversion into value-added products has been highlighted, together with the evidence of the potential social and economic benefits coming from the valorisation of microPET by way of a bio-based conversion process. Finally, an analysis has been developed to emphasize the contribution of the overall project results in the achievement of SDGs, at a public level, and of ESG, at a firm level.

Environmental sustainability of a new chain for micro-PET recovery from urban wastewater and bioconversion into amino acids

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Micro-PET can be seen as a source for bioconversion into highly valued products such as amino acids. This is the specific aim of the project called “Proteins from Plastics (ProPla)”, to extract micro-PET from urban wastewater in order to convert it through engineered *E. Coli* bacteria into amino acids [1,2]. Given the novelty of the valorization chain, no data about environmental sustainability is currently available in the literature. In this study, a Life Cycle Assessment (LCA) has been carried out to estimate the impact of each single process and estimate the most impactful phase. SimaPro v10.1 and Ecoinvent v3.10 were used as software and database in the analysis, respectively. 1 g of the target amino acid has been assumed as the functional unit. The LCA considered three major steps: (i) micro-PET extraction, (ii) transportation and (ii) valorization in a biofactory. The results highlighted that micro-PET bioconversion represents the most impactful stage of the valorization chain followed by micro-PET extraction. This is mainly due to the use of chemical reagents and electricity to maintain stirring and temperature. These results can provide a useful assessment in case of potential upgrade of the proposed chain. The results showed that both the extraction and bioconversion phases have the greatest impact.

This work was supported by the Fondazione Cariplo grant "ProPla: proteins from plastics" 2022-0631.

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From emission to resource: microfibre release and recovery potential across domestic laundry appliances

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Synthetic fibers, particularly those made of polyethylene terephthalate (PET), are widely used in clothing and household textiles, and their release during domestic laundering is recognized as a significant source of microfiber (MF) pollution [1]. Even natural fibers may still act as vectors for chemical additives and dyes [2], contributing to environmental contamination. In this context, while washing machines have been extensively studied as primary sources of MF emissions, the role of other common household appliances -such as tumble dryers and combined washer-dryers- remains underexplored.

This study aims to assess and compare MF release during the standard operation of washing machines, tumble dryers, and combined washer-dryers, using garments made of PET and cotton. Results indicate that the quantity of MFs released varies according to both the textile material and the type of appliance used. Moreover, the extent of fibre shedding is influenced not only by the type of fabric but also by the washing method—whether washing alone, washing followed by tumble drying, or combined washer-dryer cycles—highlighting the significant role of the appliance used.

Understanding how different machines and laundry practices influence microfibre release is key to defining effective mitigation strategies, including improved filtration systems, optimized programs, and appliance design solutions to minimize fibre loss. Importantly, capturing fibres directly at the appliance level also enables their recovery and valorisation through recycling and upcycling routes, transforming a diffuse pollutant into a reusable resource within a circular economy framework.

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When Waste Becomes Worth: a Biocatalytic Route from PET Bottles to Amino Acids

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The enzymatic valorization of single-use plastics, largely composed of polyethylene terephthalate (PET), represents a promising strategy for transforming waste into high-value products. In this work, post-consumer PET was enzymatically depolymerized using an engineered variant of leaf-branch compost cutinase (ΔLCC), a thermostable enzyme identified through metagenomic screening (1). A mesophilic ΔLCC variant was developed to enable integration into a whole-cell bioconversion system, as well as for coupling with downstream enzymatic valorization pathways. Variant libraries were generated by site-saturation mutagenesis and screened through a double high-throughput assay for activity at 37 °C and thermal stability. This approach led to the identification of the S101N/F243T-ΔLCC variant, which enabled efficient PET hydrolysis at 37 °C, generating terephthalic acid (TPA) and ethylene glycol under conditions compatible with microbial biotransformations.

The released TPA was subsequently funneled into a synthetic metabolic pathway by means of an engineered *Escherichia coli* RARE strain, allowing its conversion into 2-pyrone-4,6-dicarboxylic acid. This intermediate was then enzymatically processed into pyruvate using recombinant enzymes, thereby preventing its consumption by native cellular metabolism. In the final step, pyruvate was converted into enantiomerically pure alanine through an enzymatic amination reaction (2). Overall, this work demonstrates the feasibility of converting post-consumer PET into valuable biomolecules through an integrated and eco-friendly biocatalytic process.

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DRINKING WATER

Advances in scaling reduction for antiscalant-free inland desalination with high recoveries

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Scaling in inland membrane desalination plants presents a complex set of challenges that go far beyond simply limiting recovery rates. As scale builds up, it reduces the available surface area for filtration, which means less water can pass through. To keep up with production demands, operators are forced to increase pressure, driving up both energy use and thus operational costs.

But the problems don't stop there. Scaling also leads to more frequent cleaning and maintenance, which translates into higher labor and material expenses. Over time, persistent scaling can even damage the membranes themselves, shorten their lifespan and result in expensive replacements. Serious environmental concerns compound these operational problems. The use of antiscalants (AS) to combat scaling can release harmful chemicals into local waterways, endangering aquatic ecosystems. They can also cause biofouling to form on the membranes. A much bigger problem is that AS and unwanted by-products can pass through the membrane and enter the permeate. In addition to the undesirable presence of these contaminants, they may also contribute to the formation of harmful by-products in the finally disinfected water.

To tackle these challenges, and potentially reduce the reliance on antiscalants, innovative process optimization strategies are being explored. One promising approach involves operating desalination systems in a semi-batch, closed-circuit mode. This method, used in both reverse osmosis (CCRO) and nanofiltration (CCNF) systems, offers several advantages: it can significantly boost resistance to scaling and fouling compared to traditional conventional continuous flow RO (CoFRO) systems[1].

Recent pilot and bench-scale studies using real water matrices have shown that CCRO systems can either completely prevent scaling or at least delay its onset far more effectively than conventional systems. The key lies in the ability to fine-tune the process—optimizing the timing and interaction of filtration and flushing cycles, as well as adjusting flux and recovery rates to minimize the risk of scale formation. Additionally, monitoring the pH of the concentrate has emerged as a powerful tool for early detection of calcium carbonate scaling. This enables operators to take timely action, preventing the development of stubborn, irreversible scale deposits and optimizing cleaning procedures[2, 3].

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Rapid Online Microbiological Monitoring of Water Using an Automated Cell-Counting System

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Conventional microbiological testing of water frequently relies on culture-based methods that require extended incubation times, limiting the ability to detect short-term events and respond promptly. The BactoSense CORE (bNovate) is an automated online system designed to provide rapid assessment of microbial levels in water by measuring and classifying microbial cells, with results available in approximately 20 minutes.

The instrument supports continuous, unattended operation and allows configurable measurement intervals (approximately every 30 minutes to every 6 hours). It is highly sensitive, being capable of measuring just a few cells/mL, while covering covers a broad working range (up to about 5,000,000 cells/mL), and can be connected to plant information systems (e.g., SCADA) through standard digital interfaces, enabling real-time trend visualization, alarm settings, and faster operational decision-making.

Reported outputs include Total Cell Count (TCC), Intact Cell Count (ICC), and Active Cell Count (ACC), which provide a practical basis for monitoring changes in overall microbial load and cell condition over time. When installed at critical points of a water system—such as after treatment, in storage tanks, or within distribution networks—the system can support early warning, facilitate troubleshooting, and strengthen process control. This approach is intended to complement, not replace, regulatory microbiological methods and targeted pathogen testing where required.

Sustainable groundwater remediation of Cr (VI) and As (III) using rice husk–iron oxide modified adsorptive membranes coupled with Advanced Oxidation Processes

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The removal of hexavalent chromium (Cr(VI)) and trivalent arsenic (As(III)) from water remains a major challenge in environmental engineering due to their high toxicity and mobility. In this study, a rice husk biomass–based composite material modified with iron oxides, for potential application as an adsorptive membrane, was evaluated for the removal of Cr(VI) and As(III) using a sodium percarbonate (SPC)–activated pseudo-Fenton system (Gargiulo et al., 2024). SPC serves as a solid source of hydrogen peroxide, generating reactive oxygen species. Those species promote the reduction of Cr(VI) to the less toxic and less mobile Cr(III), which subsequently undergoes precipitation as chromium hydroxides (Shi et al., 2024). As(III) is oxidized to As(V), a species with a higher affinity for iron oxides, facilitating its effective immobilization through adsorption onto the iron oxide surfaces.

The results demonstrate removal efficiencies exceeding 90% for both chromium and arsenic, with significantly enhanced performance compared to the non-oxidative treatment pathway. The integration of advanced oxidation processes markedly improves pollutant degradation, highlighting the synergistic effect of the coupled system. Aligned with the principles of the blue circular economy, this technology offers a sustainable, efficient, and resource-conscious approach for groundwater remediation.

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Acknowledgment:

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A pilot scale investigation of nitrate removal from groundwater by electrodialysis: insights of batch and different feed and bleed modes of operation

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This study presents a pilot-scale investigation of nitrate removal from groundwater using electrodialysis operated in either batch or feed-and-bleed modes, with the dual goal of producing potable water from the diluate stream and valorizing the concentrate for irrigation use. Batch ED experiments were first performed to identify optimal operating conditions for nitrate removal, energy consumption, and current efficiency. Subsequently, three distinct feed-and-bleed protocols were evaluated at pilot scale over multiple cycles. Process performance was assessed based on nitrate removal efficiency, energy consumption, and water recovery. Among the tested protocols, a configuration involving complete diluate disposal and constant concentrate volume recirculation achieved the lowest final nitrate concentrations and higher water recovery, while maintaining sufficient hardness in the treated water for potable use. The resulting concentrate showed elevated nitrate levels suitable for irrigation reuse. In addition to experimental evaluation, a techno-economic optimization was conducted to assess long-term system feasibility under renewable energy supply. A photovoltaic–battery configuration was optimized for near-autonomous operation over a 20-year lifetime, demonstrating that ED-based nitrate removal can be effectively integrated with renewable energy systems at pilot scale. In this model, the Levelized Cost of Water was estimated, along with capital, operation, and maintenance costs based on weather data from the case study. Overall, the study highlights the potential of feed-and-bleed electrodialysis as a flexible and efficient approach for groundwater nitrate removal, enabling simultaneous production of potable water and irrigation-grade concentrate while supporting sustainable energy integration.

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Competitive Adsorption of Chromium(VI) and Arsenic(V) onto Polyethylenimine-Modified Silica membranes in Natural Water Matrices

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The co-occurrence of chromium(VI) and arsenic(V) in natural water systems represents a major environmental concern, particularly due to their high toxicity and the complexity introduced by naturally occurring competing ions. Both chromium(VI) and arsenic(V) are predominantly present in aqueous environments as oxyanionic species, which strongly influence their adsorption behavior and competitive interactions. In this work, the simultaneous removal of Cr(VI) and As(V) from natural water was investigated through adsorption onto silica modified with polyethylenimine (SiO_2–PEI), for potential use as an adsorptive membrane. The adsorption of Cr(VI) and As(V) is primarily attributed to electrostatic interactions between the negatively charged oxyanions and the protonated amine groups of polyethylenimine. The adsorption performance of the modified material was evaluated in a natural aqueous matrix, aiming to simulate realistic water treatment conditions. Batch adsorption experiments were carried out to examine the effects of key operational parameters, including solution pH and initial contaminant concentrations, as well as the influence of natural water components. The results indicate that SiO_2–PEI exhibits high affinity toward both oxyanionic species, enabling their concurrent removal despite the presence of competing anions. Nevertheless, the presence of coexisting water constituents adversely affected the adsorption of Cr(VI) and As(V) oxyanions, indicating competitive interactions within the natural water matrix. The findings emphasize the necessity of assessing adsorption processes under realistic environmental conditions and demonstrate the potential of polyethylenimine-modified silica as an effective adsorbent for the simultaneous treatment of multiple inorganic contaminants in natural waters.

Acknowledgment:

We acknowledge support of this work by the project "Hybrid technologies of smart membranes and novel materials for the removal of hexavalent chromium from water" (ΥΠ3ΤΑ-0560800) which is implemented under the action "SUB1.1: Clusters of Research Excellence" of the sub-action "Strategy for Excellence in Universities & Innovation" (ID 16289), Greece 2.0 – National Recovery and Resilience Fund and funded by European Union Next Generation EU.

Layer-by-Layer Functionalized Ultrafiltration Membranes as a Sustainable Solution for Cr(VI) Contaminated Waters

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Hexavalent chromium [Cr(VI)] remains one of the most hazardous inorganic contaminants in groundwater and drinking water sources due to its high toxicity, carcinogenicity, and mobility in aqueous environments. Conventional treatment methods based on chemical reduction and precipitation are often associated with excessive chemical consumption, generation of toxic sludge, and limited sustainability. In this context, membrane-based technologies offer a promising alternative, although conventional ultrafiltration (UF) membranes are inherently incapable of removing dissolved ionic species.

In the present study, the performance and regeneration potential of ultrafiltration membranes functionalized via Layer-by-Layer (LbL) assembly of oppositely charged polyelectrolytes is investigated for efficient Cr(VI) removal. Commercial UF membranes were modified by sequential deposition of anionic polyelectrolytes, as poly(acrylic acid) (PAA), and cationic polyelectrolytes, namely polyethyleneimine (PEI) or poly(diallyldimethylammonium chloride) (PDDA), followed by chemical crosslinking to enhance multilayer stability. The modified membranes were systematically characterized in terms of surface morphology, hydrophilicity, surface charge, and structural integrity. Compared to unmodified membranes, LbL-functionalized membranes exhibited smoother surfaces, increased hydrophilicity, and enhanced electrostatic interactions favorable for Cr(VI) retention. Filtration experiments demonstrated significantly improved Cr(VI) removal efficiency across a range of pH conditions relevant to drinking water treatment.

Furthermore, regeneration studies revealed that the modified membranes retained their separation performance over multiple filtration–desorption cycles, indicating strong mechanical and chemical stability of the multilayer structure and highlighting their reusability potential. The combination of high removal efficiency, low energy requirements, and effective regeneration underscores the applicability of LbL-modified UF membranes as a sustainable and cost-effective solution for chromium-contaminated water treatment.

This work contributes to the advancement of functional membrane technologies by addressing both performance enhancement and long-term operational viability, supporting their transition from laboratory-scale development toward real-world implementation.

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Acknowledgment:

We acknowledge support of this work by the project "Hybrid technologies of smart membranes and novel materials for the removal of hexavalent chromium from water" (ΥΠ3ΤΑ-0560800) which is implemented under the action "SUB1.1: Clusters of Research Excellence" of the sub-action "Strategy for Excellence in Universities & Innovation" (ID 16289), Greece 2.0 – National Recovery and Resilience Fund and funded by European Union Next Generation EU.

Investigation of the Adsorption of Caffeine and In-Situ Regeneration of Granular Activated Carbon Materials for Sustainable Drinking Water Treatment

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The presence of emerging organic contaminants (EOCs) in drinking water represents α global health challenge. Although adsorption onto granular activated carbon (GAC) is widely applied for EOCs removal, the regeneration or replacement of spent carbon is associated with significant environmental and economic burdens. This study investigates a sustainable treatment strategy that integrates adsorption and in-situ regeneration of activated carbon for the removal of organic micropollutants from drinking water.

Commercial and iron-modified granular activated carbons (F300 and F300-Fe) were used for the adsorption of caffeine as a model EOC in deionized water and tap water. Equilibrium and kinetic experiments were conducted to evaluate the effects of the water matrix composition, pH, and initial contaminant concentration. The surface of each adsorbent, including the point of zero charge, was characterized to support interpretation of adsorption mechanisms.

The in-situ regeneration of the materials was conducted using heterogeneous Fenton-based advanced oxidation processes (AOPs) in both deionized and tap water matrices with controlled hydrogen peroxide dosing. Regeneration efficiency was evaluated through adsorption capacity recovery and contaminant degradation.

Acknowledgment:

We acknowledge support of this work by the project "Hybrid technologies of smart membranes and novel materials for the removal of hexavalent chromium from water" (ΥΠ3ΤΑ-0560800) which is implemented under the action "SUB1.1: Clusters of Research Excellence" of the sub-action "Strategy for Excellence in Universities & Innovation" (ID 16289), Greece 2.0 – National Recovery and Resilience Fund and funded by European Union Next Generation EU.

Membrane Adsorbers for selective Removal of Natural Organic Matter (NOM) and their Electrochemical Regeneration

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The presence of Natural Organic Matter (NOM) challenges drinking water treatment, as it may contribute to aesthetic issues, membrane fouling, and toxic disinfection by-products (DBPs) after chlorination (Leenheer and Croué 2003). While ion exchange (IEX) and adsorption are effective for NOM removal, they suffer from pore diffusion limitations and require chemical regeneration or disposal once spent (Levchuck et al. 2018). To overcome these challenges, we investigated porous membrane adsorbers (MA) for NOM removal to reduce mass transfer limitations combined with an electrochemical regeneration method. Conventional chemical regeneration creates secondary waste and/ or is energy-intensive (e.g., carbon dioxide regeneration ion exchange, CARIX). In contrast, electrochemical regeneration offers lower energy and chemical consumption (Bagotia 2025). Electroconductive Membranes (ECMs) facilitate desorption by applying an electric potential - without chemicals - but may require membrane modification like sputter deposition of noble metals (Usman et al. 2024). To address this, we propose a method for electrochemical regeneration of loaded membrane adsorbers by applying a potential via external electrodes near the membrane adsorbers. This approach simplifies the process while maintaining effective NOM removal and regeneration.

We tested two commercial microfiltration anion-exchange membrane adsorbers (both Sartorius, Germany), Sartobind®D (weak basic, tertiary amines) and Sartobind®Q (strong basic, quaternary amines), on real groundwaters (DOC 2.6-4.6 mg/L, pH 7.6-8.5). The study employed an electro-modified membrane cell, CF16 (Sterlitech, USA), with an active membrane area of 20.6 cm^2 and electrodes in the feed and permeate channel, to evaluate both the removal and regeneration of NOM. The research focused on assessing the influence of water chemistry (pH 7-10), electrolyte concentration, and operational factors such as flux (50-400 LMH) or applied potential (-1.5 to -2.5 V Cell Potential (C.P.)).

Both weak and strong basic MAs demonstrated similar NOM removal performance, due to the positive charge of both the tertiary and quaternary amines, as well as their similar degree of functionalization. However, upon applying -2.5 V C.P., only the weak basic MA exhibited desorption, despite similar current densities. Investigation into the variation of applied C.P. revealed that both the extent of desorption and the current density increased with higher potentials.

While no regeneration of UV254 active compounds was observed at -1.5 V C.P., regeneration performance (%R) increased with C.P., reaching up to 59±3 % at -2.5 V C.P.. Increasing the flux resulted in higher charge densities, consistent with Ohm's law. While an improvement in %R was observed when the flux was increased from 50 to 100 LMH, %R decreased at higher fluxes, indicating a mass transfer limitation with an optimal flux at 100 LMH. %R was also pH-dependent, reaching 78±3 % at pH 10.

In summary, we demonstrate an electrochemical regeneration method of DOC loaded membrane adsorbers, with the functionalization of the membrane adsorbers being crucial. Deprotonatable tertiary amines achieved up to 78 % regeneration of preferred UV254 active NOM components with increasing C.P. and pH. In contrast, no regeneration was observed for intrinsic positively charged quaternary amines. Optimization of flux and potential led to higher %R and yields. Additionally, regeneration can be performed during a conventional backflush, thereby extending the lifespan of the membrane adsorbers and reducing chemical usage. The removed NOM UV254 compounds are mainly relevant for DBP-formation in chlorination.

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Assessing Removals of Pharmaceuticals in Algae Containing Water: Different Approaches in Two Lab Case Studies

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A high level of analytical uncertainty (up to 50%) represents the rarely addressed challenge in the assessment of the organic micropollutants' removal in water treatment. It will be shown how comparisons of treatments were made based on removals of ibuprofen (IB), caffeine (CF) and diclofenac (DCF) from algal water matrices (2-8 x 108 of A. platensis or C. vulgaris cells/L, initial nominal concentration of pharmaceuticals 1-2 µg/L) in a) activated carbon adsorption study [1] including errors estimation based on method's combined uncertainty and very limited number of experimental replicates (2-3 per some experiments, mainly in long time intervals) and b) in the study on ultrafiltration combined with eco-adsorbent including also natural water in at least 4 but mostly 8 replicates for all experiments in short intervals. The latter used basic statistical treatment by non-parametric Wilcoxon/Kruskal-Wallis test. Error calculation in the first case buffered variability of removals depending on algae type, growth phase, presence of particulate or dissolved organic carbon, and pre-chlorination. Only rarely, but without consistent experimental repeatability, negatively charged IB and DCF showed removal variations ≥30% (the value used since in the analytical quality checks signals are allowed to vary ±30% of expected value [2]). In the second study, various dosing modes of eco-adsorbent were tested. Both analytically and statistically significant differences were possible to capture for certain conditions. To overcome difficulties, future work should include long term tests with QA/QC protocols including higher number of replicates in real conditions.

Acknowledgment:

The research is funded by BMBF (01DS21012A) and supported by the Ministry of Science, Technological Development and Innovation of the R Serbia (451-03-137/2025-03/200125 and 451-03-136/2025- 03/200125).

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Surface-flow interplay shapes biofilm structure: Implications for resilient drinking water systems

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Microorganisms can adhere to surfaces and form structurally complex and dynamic communities known as biofilms. This growth lifestyle is widespread, enabling microbes to withstand challenging environments while benefiting from co-living interactions. Biofilms thrive under wet conditions, such as in drinking water distribution systems, where they pose significant threats to water quality, infrastructure integrity, and hydraulic efficiency. This work investigated biofilm development on diverse surfaces under varied flow conditions employing a combination of batch and flow milli-channel experiments, advanced imaging techniques, including fluorescence microscopy and optical coherence tomography, as well as quantitative image analysis. Our findings revealed that i) shear flow amplified the role of surface topography in contrast to static conditions, ii) flow path geometry strongly affected biofilm patterns, and iii) surface material modulated biofilm thickness, structural uniformity, and persistence. Notably, identical flow geometries elicited different biofilm responses depending on the surface, highlighting a complex interplay between flow dynamics and surface properties. Consequently, manipulation of this interaction to reshape the microbial landscape could effectively mitigate biofilm accumulation, offering a green, context-specific strategy to enhance the resilience of drinking water systems while minimizing chemical interventions.

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Monitoring of Polycyclic Aromatic Hydrocarbons for Drinking and Surface Water of Cyprus

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Polycyclic aromatic hydrocarbons (PAHs) are defined as persistent organic pollutants of significant environmental and public concern due to their toxicity, carcinogenicity and widespread occurrence. Within the European Union, the regulatory control of PAHs is established through the Drinking Water Directive and the Water Framework Directive, which define parametric values and environmental quality standards for selected PAHs.

The present study presents the results of systematic monitoring, which was conducted in order to assess the occurrence and distribution of priority PAHs in drinking water and selected surface water bodies, such as reservoirs, across Cyprus over the period 2021-2025.

Moreover, this study delineates the development, validation and application of a sensitive analytical method for the determination of the 15 priority PAHs listed by the United States Environmental Protection Agency. Water samples were subjected to solid-phase extraction (SPE) using C18 cartridges. The PAHs were eluted using an acetonitrile/dichloromethane solution. The samples were concentrated under nitrogen flow and subsequently reconstituted in acetonitrile. Quantitative analysis was conducted utilising a liquid chromatography apparatus, which was integrated with a multi-wavelength fluorescence detector, capable of measuring across four distinct excitation/emission wavelengths. The calibration procedure incorporated multi-level calibration curves for each matrix. The performance of the method was evaluated in terms of linearity, limits of detection (LOD), limits of quantification (LOQ), recovery, repeatability, matrix effect and expanded uncertainty. In order to ensure the maintenance of standards, both blank and spiked samples were incorporated into each analytical batch.

The State General Laboratory (SGL) is the official government laboratory of Cyprus responsible for the monitoring and control of water quality. It performs the PAHs analysis on behalf of the Public Health Services for drinking water and the Water Development Department for surface water, in accordance with cooperation protocols established on an annual basis between the respective departments. The method has been validated and accredited and the yearly laboratory participation in interlaboratory comparisons is satisfactory.

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Variations of Organic Carbon and Inorganic Ions in Water Resources: Impacts of Prolonged Drought

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The State General Laboratory, as the competent laboratory for the control of drinking water quality, applies analytical methods within the framework of a Quality Management System in accordance with ISO/IEC 17025:2017. The control and monitoring of chemical parameters are carried out in compliance with the requirements of Directive (EU) 2020/2184 (Law 46(I)/2023), as well as on the basis of Directive 2000/60/EC for surface waters (Law 13(I)/2004).

The approach is based on the systematic assessment of the entire water supply chain, from surface waters (reservoirs), boreholes, and water production points, to treated water from water treatment plants and desalination units, and ultimately to the consumer's tap.

This study presents data on the determination of Total Organic Carbon (TOC), chloride anions by ion chromatography and titrimetric methods, as well as sodium cations by flame photometry. The impact of prolonged drought on the concentration levels of ions and TOC in dams and water treatment plants supplying the drinking water distribution network is evident. An increased organic load is observed, attributed to enhanced evaporation and low water renewal rates in reservoirs.

In boreholes intended for water supply, drought conditions lead to increased salinity due to evaporation, reduced aquifer recharge rates, and salinization as a result of potential seawater intrusion.

The findings highlight the importance of continuous monitoring of organic carbon and ionic load as indicators of changes in water resource quality, particularly under conditions of prolonged drought. The comprehensive evaluation of these parameters constitutes a critical tool for supporting sustainable water management and safeguarding public health.

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Establishing In-House Illumina MiSeq Capacity for Antimicrobial Resistance Monitoring in Drinking Water and Wastewater

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Antimicrobial resistance (AMR) is recognized as a major global public health threat, with aquatic environments increasingly identified as important reservoirs and transmission pathways for antimicrobial resistance genes (ARGs). Drinking water distribution systems and wastewater networks can reflect both community-level antimicrobial use and environmental dissemination of resistance determinants, highlighting the need for robust, culture-independent surveillance approaches. Recent advances in next-generation sequencing (NGS) enable comprehensive profiling of resistomes directly from environmental matrices, overcoming limitations of traditional culture-based methods.

This work presents the establishment of in-house Illumina MiSeq sequencing capacity at QLAB for the genomic monitoring of AMR in drinking water and wastewater samples. The implemented workflow includes sample concentration, DNA extraction, library preparation, and high-throughput sequencing, followed by bioinformatic analysis for ARG detection and resistome characterization. Both drinking water and wastewater samples are analyzed using metagenomic approaches, allowing the detection of a broad spectrum of resistance determinants across multiple antimicrobial classes. The use of Illumina MiSeq provides a flexible and scalable platform suitable for routine surveillance and targeted monitoring applications.

The developed framework enables standardized rapid data generation and local analytical autonomy. By integrating NGS-based resistome analysis into water quality monitoring, this approach contributes to One Health–oriented AMR surveillance strategies and supports evidence-based risk assessment. The establishment of in-house sequencing capacity strengthens preparedness for emerging AMR threats and provides a foundation for future longitudinal studies linking environmental resistomes with public health indicators.

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INNOVATIVE MATERIALS FOR WATER AND WASTEWATER TREATMENT

Characterization and Catalytic Potential of Novel Biofunctionalized Composites for the Removal of Phenolic Compounds from Wastewater

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We are living in a challenging world, and each of our actions, especially in science, has an impact. It is of utmost importance to have a broad perspective and look deeply into the vast pool of pollutants in all environmental compartments, with special attention to aquatic ecosystems. A multidisciplinary approach is necessary to identify toxicological threats, develop chemical methodologies for qualitative and quantitative analysis, and create modes of action to find solutions to prevent, or at least decrease, harmful effects on ecosystems and human health.

Water pollution is a global problem. Phenol and their derivatives are among many threats, highly ranked on the list of hazardous and persistent contaminants. Our research is oriented toward the development of biofunctionalized magnetite-geopolymer composites for the effective removal of phenolic pollutants from wastewater. Biofunctionalized magnetite-geopolymers (Geo-MP composites) were produced using various geopolymers based on bentonite, kaolin, and allophane, Fe(II) and Fe(III) sulfate salts, and plant extracts. The best candidates were subjected to further procedures for enzyme peroxidase immobilization. Prepared materials and biocatalysts were characterized using X-ray diffraction (XRD), scanning electron microscopy (SEM) coupled with energy-dispersive X-ray spectroscopy (EDS), and Fourier-transform infrared spectroscopy (FTIR). The enzymatic activity of biocatalysts, impact of different pH and temperature on the enzyme activity, storage stability, the impact of the presence of metal ions and organic substances on enzyme activity, and reusability, were also investigated. The results were compared with those for the enzyme in free form.

The innovative biocatalyst obtained by immobilizing peroxidase enzyme onto biomagnetite particles, as well as on M-GP composites, demonstrates high efficiency, about 90%, in the removal of investigated phenolic compounds from water and paves the way for the development of green heterogeneous catalysts aligned with the principles of sustainability, resource efficiency, and environmental safety.

Acknowledgement:

This research was supported by the Science Fund of the Republic of Serbia, #GRANT No 7464, Novel Bio-linked Magnetite/geopolymer Composites in Phenol-containing Wastewater Treatment: Toward Zero-waste Technology - BioCompWaterClean.

La_2O_3-MgO functionalized activated carbon /chitosan beads from olive stones for Cr(VI) removal from water

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Cr(VI) is an extremely dangerous and potent carcinogenic compound often associated with industrial activities such as metal plating, leather tanning, and the production of wood preservatives. As a result, WHO set the maximum allowed concentrations in surface water and drinking water being less than 0.1 and 0.05 mg/L, respectively. Among the techniques employed for water treatment, adsorption is regarded as a favorable option due to its simplicity of operation and high efficacy. In the present work, Activated Carbon (AC) derived from olive stones is functionalized with MgO-La_2O_3, and combined with Chitosan (Cs) for the fabrication of composite beads. Research tends to focus on the use of agricultural by-product solid wastes, including fruit and vegetable residues, to create economical adsorbents as substitutes for coal-based activated carbon. Among them, olive stones (OS) have been successfully utilized for the adsorption of heavy metal ions from water. Cs is widely selected for the fabrication of adsorbent beads, owing to its biocompatibility, biodegradability, and remarkable functional attributes. As a natural polysaccharide it aligns with sustainability goals and contains several amino and hydroxyl groups that enhance interactions with pollutants. The adsorption effectiveness towards Cr(VI) was assessed by batch and column adsorption tests, while the morphology and structure were extensively characterized. According to the results, the optimal pH value was found to be 3.0, suggesting electrostatic interactions as the driving force for adsorption. Isothermal data fitted better to Freundlich model, indicating multilayer adsorption, achieving an adsorption capacity of 38 mg/g after 1h of contact time and dosage of 0.5 g/L.

Acknowledgements:

We acknowledge support of this work by the project "Hybrid technologies of smart membranes and novel materials for the removal of hexavalent chromium from water" (ΥΠ3TA-0560800) which is implemented under the action "SUB1.1: Clusters of Research Excellence" of the sub-action "Strategy for Excellence in Universities & Innovation" (ID 16289), Greece 2.0 – National Recovery and Resilience Fund and funded by European Union Next Generation EU.

Fabrication of 3D-printed membranes for wastewater treatment

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The adoption of 3D printing in water/wastewater treatment, applying membrane separation processes, may successfully prevent the waste of large amounts of solvents and, thus, reduce the high carbon footprint of conventional polymeric membrane fabrication. In addition, the capability to precisely fabricate objects with specific shape, structure and surface characteristics offers the possibility to construct custom-made structures suitable for the requirements of specific membrane separation processes. The 3DInnomem project aims in the fabrication and characterization of innovative 3D-printed membranes, by a methodology consisting of subsequent stages of progressive examination of the new 3D structures and their performance during surface water or municipal wastewater treatment.

In this frame, several materials (polymers, hydrogels, ceramics) were evaluated for 3D-printing based on their physicochemical properties, the fabrication process parameters and the potential for custom-made membrane structures able to incorporate anti-fouling or disinfectant agents. The performance of printed membranes was evaluated in a laboratory membrane cell operating with cross-flow configuration of packed membranes by monitoring the trans-membrane pressure for various flowrates, temperature and outflow samples. Experiments were carried out using a synthetic wastewater input consisting of proteins, peptides, amino acids and salts at high concentrations (meat extract, peptone, urea). The separation rate of suspended solids and the appearance of membrane fouling were identified and correlated to the geometrical and internal characteristics of printed membranes including the pores and channels size, shape and density as well as the hydrophilicity of the material.

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3DInnomem website: https://aclab.web.auth.gr/3dinnomem

Acknowledgments

The research project is implemented in the framework of H.F.R.I. call “3rd Call for H.F.R.I.’s Research Projects to Support Faculty Members & Researchers” (H.F.R.I. Project Number: 24958).

Multifunctional Porous Carbon Textiles decorated with Bimetallic MOFs for Air & Water Decontamination via Adsorption-Catalysis Synergy

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The development of advanced materials for air and water purification, ranging from household filtration systems to protective media for crises such as gas masks, demands innovative and multifunctional adsorbents. Nanoporous carbon textiles (C-Texts) are highly promising due to their high surface area, tunable surface chemistry, low weight, and cost. However, optimizing C-Texts remains challenging, and two approaches are followed: (i) tuning of key physicochemical features and (ii) nanoengineering through the incorporation of active nanophases. Organic micropollutants, including pharmaceuticals, represent a persistent source of water contamination, while chemical warfare agents (CWAs), such as blister and nerve agents, continue to pose serious threats.

This work highlights strategies to enhance the multifunctional performance of C-Texts for both air and water decontamination. We first evaluated the adsorption efficiency of commercial and chemically modified C-Texts, identifying the physicochemical parameters most critical to performance, while systematically investigating the influence of humidity under realistic conditions. Further improvements were achieved by developing scalable, cost-effective methods to decorate C-Texts with minimal loadings of mono- and bimetallic Metal-Organic Frameworks (MOFs), specifically ZIF-based active phases. The resulting hybrid textiles exhibited superior removal of diclofenac from water, and detoxification of CWAs vapors and droplets, alongside extra-high antibacterial efficiency. These enhancements are attributed to homogeneous nanoparticles dispersion and synergistic adsorption-catalysis interfacial effects, enabling efficient catalytic detoxification coupled with strong and stable retention of hazardous molecules.

Acknowledgements:

The work is financially supported by the National Science Centre (NCN) of Poland via the SONATA-19 grant 2023/51/D/ST5/01915 (PI: D. Giannakoudakis).

Hach: Integrated Water Analysis Solutions for Reliable, Compliant, and Efficient Water Management

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Ensuring reliable water quality is a global priority for municipalities and industries facing increasing regulatory pressure, operational complexity, and sustainability targets. Hach, a global leader in water analysis and part of the Veralto Water Quality platform, delivers integrated laboratory, online, and field analytical solutions designed to make water monitoring efficient, sustainable and user-focused. With more than 80 years of innovation and one of the largest dedicated water analysis sales and service network, Hach supports customers worldwide in achieving confident, data-driven water quality management.

Hach's mission is to ensure water quality worldwide through trusted analytical solutions and expert support. Its vision is to continuously improve water analysis by making it faster, simpler, and more informative through innovation, reliable technologies, and strong customer partnerships, enabling more confident and proactive water quality decisions.

Hach offers a comprehensive portfolio of measurement technologies, software platforms, and expert services across the full water cycle — from source water and drinking water treatment to municipal and industrial wastewater, ultrapure and steam water systems, and specialized applications in sectors such as power, food and beverage, chemical processing, maritime, pulp and paper, and mining.

A key focus for Hach is the digitalization through connected water intelligence systems that unify instrument management, data visibility, and process control. Claros digital platform enables real-time monitoring, predictive diagnostics, and remote sensor management, helping utilities and industries improve regulatory compliance, reduce energy and chemical consumption, minimize downtime, and optimize treatment performance.

By combining robust analytics, application expertise, and service support, Hach demonstrates how end-to-end water analysis strategies can enhance operational resilience, support sustainability goals, and protect public and environmental health. This integrated approach provides a scalable framework for smarter water quality management at global and local levels.

SMWCNT-mediated Bi_2MoO_6/N-rich carbon nitride indirect S-scheme heterojunctions: 3D conductive network-built-in electric field synergy drives charge transfer for enhanced photocatalytic performance

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Rational interface and charge-transport engineering were leveraged to construct an indirect S-scheme Bi_2MoO_6/N-rich carbon nitride heterojunction (BMO-CNTs-CN) mediated by multi-walled carbon nanotubes (MWCNTs). The MWCNTs introduce a three-dimensional conductive framework that bridges Bi_2MoO_6 and g-C_3N_5, suppresses the oxidative re-stacking of g-C_3N_5 nanosheets, and provides rapid electron-conduction channels. Benefiting from this 3D network and the indirect S-scheme architecture, the BMO-CNTs-CN photocatalyst achieves removal efficiencies of 92.96% (TC, 50 min), 95.85% (RhB, 40 min), and 93.01% (MO, 30 min). Density functional theory jointly substantiate band bending and a built-IEF, confirming efficient photogenerated-carrier separation and transfer. The synergistic action of the IEF and photon energy accelerates carrier transport, overcoming charge-transfer limitations typical of conventional heterojunctions and thereby enhancing photocatalytic degradation of diverse pollutants.

Enhanced removal of hexavalent chromium using chitosan/activated carbon derived from pine needles and modified with $AlCl_3 \cdot 6H_2O$

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Heavy metal contamination of water presents serious environmental and health risks due to toxicity and bioaccumulation. Hexavalent chromium (Cr(VI)), commonly released from industrial sources, is especially hazardous because of its high solubility, mobility in water, and carcinogenic nature. In the current study, a novel chitosan/pine needle-derived activated carbon modified with $AlCl_3 \cdot 6H_2O$ (CS/ACPN@Al) was synthesized as a high efficiency adsorbent for Cr(VI) removal. Chitosan/pine needle-derived activated carbon powder (CS/ACPN) was synthesized and used for comparison purposes. These modifications create new active sites, enhance surface functionality, and increase porosity, resulting in greater adsorption capacity and fast Cr(VI) removal rate. The synthesized adsorbents CS/ACPN and CS/ACPN@Al, were characterized to evaluate their adsorption potential. FTIR confirmed functional groups critical for Cr(VI) binding and the subsequent adsorption of Cr(VI) onto the active surfaces. XRD revealed the successful incorporation of ACPN@Al into CS matrix, as well as SEM-EDS determined morphology and elemental composition of surface. The adsorption performance was further examined by optimizing key parameters, including pH, contact time, adsorbent dosage, and initial chromium concentration. According to the results, almost total Cr(VI) removal achieved (>98%) at pH 3.0. Overall, the adsorption evaluation combined with the analytical results highlights how structural and surface modifications enhance the adsorptive properties of chitosan, making the composite materials highly effective for the removal of Cr(VI) from aqueous solutions.

Acknowledgements:

We acknowledge support of this work by the project "Hybrid technologies of smart membranes and novel materials for the removal of hexavalent chromium from water" (ΥΠ3ΤΑ-0560800) which is implemented under the action "SUB1.1: Clusters of Research Excellence" of the sub-action "Strategy for Excellence in Universities & Innovation" (ID 16289), Greece 2.0 – National Recovery and Resilience Fund and funded by European Union Next Generation EU.

Screening Significant Operational Parameters for Coagulation-Flocculation Treatment of POME Using Hybrid Coagulant of Copperas-Sodium Aluminate

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Palm oil mill effluent (POME) is extremely polluted wastewater which rich in organic matter and suspended solids, making it a challenging environmental issue in industrial wastewater management. The direct release of untreated POME without any treatment can harm aquatic life, contaminate soils, and degrade ecosystems. The preliminary analysis of the POME exhibited a concentrated turbidity and total suspended solids (TSS) of 1776.67 NTU and 2853.33 mg/L, respectively. Focusing on the removal efficiencies of turbidity and TSS, this study aimed to identify and evaluate the significant factors affecting the removal of turbidity and TSS through a design of experiment approach. Four operational factors were investigated: coagulant dosage (500 – 2500 ppm), initial pH (4 – 7), stirring speed (100 – 300 rpm), and flocculation time (10 – 30 minutes). A two-level factorial design (TLFD) was used to determine the most influential factors and interaction effects on these parameters. Turbidity was measured using a turbidity meter, while TSS was quantified with a Hach Spectrophotometer. The maximum removal efficiencies of 93.24% turbidity and 93.76% TSS were achieved under the optimal condition of a coagulant dosage of 2500 ppm at pH 9, stirring speed of 100 rpm, and flocculation time of 10 minutes. The TLFD analysis also pinpointed the key factors that are most influential for further optimization using Response Surface Methodology (RSM) to enhance overall treatment efficiency.

Keywords: Palm oil mill effluent; hybrid coagulant; coagulation-flocculation

Bioaugmentation for odor and corrosion control in sewage networks: long-term performance evaluation of a full-scale application

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The prevalence of anaerobic conditions (septicity) in sewage networks results in malodor formation due to the biological production of odor-causing compounds, such as hydrogen sulfide (H_2S) by Sulfate Reducing Bacteria (SRB). Many Municipal Enterprises for Water Supply and Sewerage face significant odor problems in urban environments originating from sewage networks, mainly during summer periods when H_2S production becomes particularly intense. Apart from causing odor issues, the production of H_2S also results in severe corrosion phenomena of hydraulic structures. The produced H_2S is transferred into the gas phase of pumping stations and gravity sewers, where it is subsequently oxidized by sulfur-oxidizing bacteria into sulfuric acid (H_2SO_4), which attacks concrete and metals, ultimately resulting in their deterioration.

In order to cope with the adverse effects of sewerage septicity, the bioaugmentation method has been successfully applied during the past five (5) years in the sewage network of Rethymno city (Crete). This method is implemented through controlled dosing of specialized microbial mixtures, resulting in the biological oxidation of the hydrogen sulfide already generated in the sewer environment. Furthermore, microorganisms colonize the network's biofilm and inhibit further H2S production by selectively out-competing SRB. The method application resulted in a significant reduction (> 80%) of H_2S concentrations in the wastewater bulk phase, accompanied by a marked mitigation of odor nuisance within the urban environment. The effectiveness of the method was further substantiated by a public survey conducted among local residents, in which more than 85% of respondents reported noticeable improvement in odor-related conditions.

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Membrane Distillation: An Innovative Solution for High-Salinity Mining Effluent Treatment

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The River Llobregat in Spain has long been affected by pollution from potash mining in the Bages region, where saline mining effluents rich in chlorides and other salts have entered the river system through runoff, leaks, and groundwater contamination. These discharges have increased the river's salinity, degrading aquatic ecosystems, harming agriculture, and complicating the treatment of drinking water for the Barcelona metropolitan area, which relies heavily on the Llobregat. The problem has persisted for decades due to large tailings piles and insufficient containment, prompting costly remediation measures such as brine collectors.

These wastewaters are hard to treat with conventional membranes because their extremely high salinity creates high osmotic pressure, requiring very high operating pressures and energy use. They also contain ions and solids that cause severe membrane fouling and scaling, reducing efficiency and membrane life.

Membrane distillation can be a promising solution for these wastewaters because it is driven by a temperature gradient rather than high pressure, allowing it to handle extremely high salinity streams.It can achieve high salt rejection while operating at lower pressures and potentially using low-grade or waste heat from mining operations.

Additionally, membrane distillation can concentrate brines beyond the limits of conventional membranes, reducing liquid waste volumes and improving overall water recovery.

In the context of the intelWATT project a TRL7 solar assisted membrane distillation unit was developed to recover both water and valuable substances such as magnesium rich compounds.

The results indicated that although the treatment of these wastewaters is challenging there is great potential for the application of membrane distillation for achieving results where the conventional processes are limited

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Recovery of nitrates from contaminated effluents: green ammonia production over N-doped transition metal catalysts

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The electrochemical conversion of nitrate to ammonia, an added value product, creates an opportunity for the valorization of contaminated effluents. This process is an alternative to the Haber-Bosch synthesis, as it allows the use of renewable energy sources to produce green ammonia, which is an important alternative hydrogen carrier [1]. However, efficient noble metal-free catalysts still require further developments before large-scale use.

In this work, nitrogen doped carbon-supported iron/copper catalysts were evaluated as in the nitrate conversion to ammonia. Nitrogen was introduced by doping of the carbon support (FeCu/CB-N) or by direct addition to the metallic precursors (N-FeCu/CB). While the N-doped support led to the formation of crystalline copper oxide phases, nitrogen in the metals promoted the formation of metallic copper (Figure 1a). The basic character of the N-doped support improved conversion rate (Figure 1b, X NO_3^-), while the presence of the metallic copper promoted ammonia selectivity (S NH_4^+). N-doping can thus be used to improve performance of transition metal catalysts for nitrate conversion to ammonia.

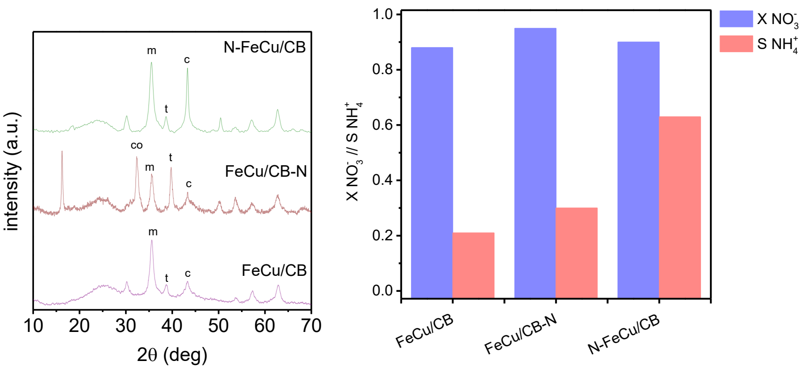

Figure 1. XRD patterns of catalysts (a, co = copper oxide, m = magnetite, t = tenorite, c = metallic copper), and nitrate conversion and ammonia selectivity after 8 h of reaction (b).

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MXene Photocatalysts for Emerging Water Pollutants Abatement

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Environmental problems associated with water pollution have raised serious concerns. Water contaminants of emerging concerns pose significant environmental and public health challenges due to their persistence and toxicity in aquatic systems. In this context, photocatalytic processes have been studied and were proven to be promising and environmentally friendly methods for water treatment. In this study, MXene synthesis was explored using Ti_3AlC_2 (MAX phase) as the precursor via a conventional chemical etching process with hydrofluoric acid (Alhabeb et al., 2017). Heterojunctions were also introduced using hydrothermal and precipitation synthesis techniques. The heterojunctions were prepared coupling MXene with ZnO and CeO_2. The photocatalytic activity of the developed materials was assessed by using the following model compounds: antibiotic sulfamethoxazole (SMX) and phenol, persistent contaminants poorly eliminated by conventional wastewater treatments. Under simulated irradiation ($\lambda > 340$ nm) and among the tested photocatalysts, MXene-ZnO-CeO_2 was the fastest in degrading both SMX and phenol (pollutant 10 mg L-1; catalyst 200 mg L-1), reaching full degradation in less than 2 hours for both pollutants. MXene-derived photocatalysts exhibited efficient photodegradation, achieving high removal efficiencies due to their excellent electrical conductivity, large surface area, and the ability to facilitate charge separation, which render them as attractive candidates for photocatalytic removal of pollutants as well as improvement of photocatalytic performance of semiconductor catalysts (Iravani & Varma, 2022). These findings highlight the potential of MXene-based photocatalysts in addressing recalcitrant organic contaminants in wastewater treatment applications.

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Redefining Targeted Environmental Analysis with Integrated DART – Triple Quadrupole Technology

George Gourgouletis

Target Analysis

Introducing a fully integrated Direct Analysis in Real Time (DART) ion source coupled to a high-performance triple quadrupole mass spectrometer.

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Direct ambient ionization screening and seamless switching to conventional LC-MS/MS operation within a single benchtop system improve laboratory throughput while minimizing solvent consumption, reducing operational costs, and lowering the environmental footprint of routine analysis.

Industrial wastes utilization for CO_2 capture and accelerated carbonation in a hollow-fiber membrane contactor

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Novel technologies for carbon dioxide capture and utilization (CCU) and accelerated carbonation increasingly employ gas-liquid membrane contactors for post-combustion CO_2 capture [1]. This study investigates the application of hollow fiber membrane contactor technology for simultaneous CO_2 capture from energy-intensive industrial flue gases and the acceleration of mineral carbonation using ion-rich industrial waste streams (e.g. lime slurries, desalination brines, upgraded brine solutions) in a single-step multiphase process [2],[3]. The proposed concept serves as a key enabler of circular economy pathways across several industrial sectors (e.g., cement industry, steel production), by providing a viable CCU option while supporting the production of value-added materials. Specifically, industrial waste streams are exploited to permanently store CO_2 in the form of Ca/Mg-carbonates, thereby contributing to climate change mitigation. An experimental investigation is conducted to evaluate CO_2 capture from representative industrial off-gases, using a lab-scale precipitator reactor, with simulated, real, and upgraded brines serving as potential absorption media. Comparative experiments are also performed using membrane gas absorption (MGA) with commercial polymeric membrane contactors to assess differences in CO_2 capture and mineralization performance. The synthesized nanocomposite particles are extensively characterized by dynamic light scattering (DLS), X-ray diffraction (XRD), thermogravimetric analysis (TGA), scanning and transmission electron microscopy (SEM/TEM), and Fourier-transform infrared spectroscopy (FTIR). Under the investigated operating conditions, the results demonstrate the technical viability of the proposed membrane-based concept, achieving high CO_2 capture and conversion efficiencies, while enabling the production of carbonate nanoparticles with controllable structural, morphological and mechanical properties.

Acknowledgments

This research has been produced with the financial support of the Clean Energy Transition Partnership (CETPartnership), the European Partnership under the 2022 Joint Cal for research proposals(CETP-2022-00074 BUCK$$$ project), co-funded by the European Commission (GA N°101069750) and with the funding from GSRI, EUDP and MoE.

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Assessment of residual crude oil in water samples by Gas Chromatography–Mass Spectrometry after removal and bioremediation using biochar-immobilized microorganisms

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Crude oil contamination of aquatic systems remains a serious environmental concern, and conventional remediation methods are often costly and inefficient. Biochar, produced by pyrolysing organic waste, has strong potential to remove petroleum pollutants due to its strong adsorptive properties and its ability to serve as a carrier for hydrocarbon-degrading microorganisms. Therefore, bioremediation has emerged as a more environmentally friendly alternative, particularly through the use of microorganisms immobilised on solid carriers [1, 2].

In this study, crude oil removal from water samples was investigated using biochar, microbial consortia, and their combination under laboratory conditions over a period of up to 96 days. Removal efficiency was determined gravimetrically, and changes in the composition of residual oil were analysed by gas chromatography–mass spectrometry (GC–MS). The microorganisms were isolated from oil-contaminated soil, immobilised on biochar produced by pyrolysis of wheat straw pellets and sewage sludge at 550 °C, and the experiment lasted 96 days.

The results showed that systems combining biochar and immobilised microorganisms achieved the highest removal efficiencies, exceeding 95% of total crude oil. GC–MS analysis indicated preferential biodegradation of saturated hydrocarbons, particularly n-alkanes and isoprenoids, while aromatic and polycyclic hydrocarbons exhibited limited degradation. These findings demonstrate the effectiveness of biochar-immobilized microorganisms as a sustainable approach for the remediation of oil-contaminated aquatic systems.

Acknowledgments

The study was financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia (451-03-136/2025-03/200168 and 451-03-136/2025-03/200026).

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Mesoporous organic carbon materials as a sorbent for pharmaceutical removal from water

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The increasing presence of pharmaceutical compounds in water poses significant ecological and public health issues. Adsorption is one of the most common techniques used because it is simple, affordable, and effective. Carbon materials, such as biochars, have high surface areas and many active sites for binding pharmaceuticals. In this work, organic carbon materials were synthesized through radical polycondensation of resorcinol and formaldehyde, modified by heteroatom incorporation, and carbonized at 900°C. The characterization methods confirmed the presence of organic functional groups and successful incorporation of heteroatoms into the carbon structure. The resulting materials have improved structural surfaces and morphological features, high surface area, and large pore diameters. All samples are primarily mesoporous. Pharmaceutical removal experiments demonstrated satisfactory removal efficiency (over 90%) and high adsorption capacities (between 200-300 mg/g). Carbon materials modified with heteroatoms show enhanced adsorption properties compared to pristine carbons.

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Hexavalent chromium in water: Sustainable adsorbents and regulatory compliance

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Water contamination by hexavalent chromium (Cr(VI)) poses serious environmental and public health risks due to its high toxicity and carcinogenicity. This work evaluates the current literature on strategies for Cr(VI) removal, focusing on activated carbons produced from agrofood and forestry residues. Key factors affecting adsorption efficiency include the type of biomass, the activation method, and surface modification, such as the incorporation of metals (lanthanum, magnesium, aluminum, nickel) or functional polymers such as chitosan. These modifications enhance the adsorption of anionic Cr(VI) species, improving selectivity and capacity. A central aspect of this analysis is the regulatory framework: Cr(VI) is strictly limited to 50μg/L by the World Health Organization, 100μg/L by the US Environmental Protection Agency, and the European Union has set a limit of 25μg/L by 2036. The review links technological approaches directly to regulatory requirements, providing guidance for the design of high-performance adsorbents that meet current and future standards. The findings highlight the potential of sustainable, low-cost adsorbents derived from waste biomass to effectively reduce Cr(VI) concentrations in water, supporting both environmental protection and circular economy principles.

Acknowledgements:

We acknowledge support of this work by the project "Hybrid technologies of smart membranes and novel materials for the removal of hexavalent chromium from water" (ΥΠ3ΤΑ-0560800) which is implemented under the action "SUB1.1: Clusters of Research Excellence" of the sub-action "Strategy for Excellence in Universities & Innovation" (ID 16289), Greece 2.0 – National Recovery and Resilience Fund and funded by European Union Next Generation EU.

Plasma-derived Few-Layer Graphene for Water Remediation and Hydrogen Storage

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Graphene and other carbon-based nanomaterials have attracted significant interest in energy storage and environmental remediation due to their high surface area, tunable surface chemistry and exceptional electrical and mechanical properties. In this study, plasma-derived few-layer graphene (FLG), featuring surface defect engineering and a specific surface area of 614 m^2/g, was systematically investigated with respect to its structural, morphological, and adsorption properties. The material was characterized using X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS), gas sorption analysis, scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Structural analyses confirmed the high crystallinity and few-layer morphology of FLG, while surface chemical analysis revealed the presence of oxygen-containing functional groups favorable for dye adsorption. The adsorption behavior of crystal violet (CV) on FLG was evaluated under various physicochemical conditions, including different pH values (4, 7 and 9), contact times and temperatures (45 °C and 55 °C). Steady-state adsorption experiments demonstrated that temperature influenced CV uptake, while comparable removal efficiencies exceeding 95 % were observed across all pH values. Kinetic studies indicated a rapid adsorption process, highlighting the high affinity of FLG towards CV molecules. In addition, preliminary H_2 adsorption measurements revealed a promising candidate for H2 storage applications, underlining the multifunctional character of the plasma-treated FLG material. Overall, this study highlights the dual potential of FLG as an efficient adsorbent for dye removal and as a promising candidate for hydrogen storage, emphasizing the versatility of graphene-based materials for combined environmental and green energy applications.

Manganese Removal Using Novel Biofunctionalized Geopolymer Composite: Synthesis, Characterization, and Adsorption Performance

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Rapid urbanization, industrialization, and climate change are increasing global concerns regarding water pollution (1). In this context, elevated manganese concentrations in water pose a significant technical and environmental problem. Long-term exposure can also have adverse health consequences. Modern adsorption materials based on expensive or synthetic adsorbents are efficient but often costly and environmentally harmful, making industrial byproduct-based geopolymers a promising sustainable alternative (1).

The current study aims to evaluate biofunctionalized magnetite-bentonite-based geopolymer composites synthesized in the presence of tangerine peel extract as a new, low-cost, and potentially alternative adsorbent for removing manganese ions from groundwater with high manganese ion content, in the Novi Sad area, Republic of Serbia. The composite's characteristics were analyzed using scanning electron microscopy (SEM) with energy-dispersive X-ray spectroscopy (EDS), Fourier transform infrared spectroscopy (FTIR), and X-ray diffraction (XRD). Textural characteristics were examined using the BET/BJH method.

The composite material achieved over 97% efficiency in removing manganese ions and reached adsorption equilibrium in just 5 minutes. It reduced the manganese ion concentration in water to below 50 µg/l, meeting the hygienic quality standards for drinking water in the Republic of Serbia. These results indicate that converting agro-industrial byproducts into effective adsorbents for manganese removal is a highly promising approach.

Acknowledgement:

This research was supported by the Science Fund of the Republic of Serbia, #GRANT No 7464, Novel Bio-linked Magnetite/geopolymer Composites in Phenol-containing Wastewater Treatment: Toward Zero-waste Technology - BioCompWaterClean.

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Adsorption of Congo Red onto Cetylpyridinium-Modified Phillipsite: Kinetic Behavior and Effect of Adsorbent Dose

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The removal of synthetic dyes, such as Congo red (CR), from aqueous solutions remains a critical challenge in wastewater treatment due to their high stability and adverse environmental impact [1]. In this study, the adsorption performance of cetylpyridinium-modified phillipsite toward the anionic dye CR was investigated, with particular emphasis on adsorption kinetics and the effect of adsorbent dose. Two organo-phillipsite samples, P1 and P2 (prepared using cationic surfactant cetylpyridinium chloride at 100% and 200% of the external cation exchange capacity, respectively), were used as adsorbents. As these materials were previously synthesized and fully characterized [2], the present work focuses exclusively on their adsorption behavior. Batch adsorption experiments were carried out using an initial CR concentration of 25 mg L^{-1}. Kinetic studies were performed for contact times up to 180 min using an adsorbent dose of 0.5 g L^{-1}, while the effect of adsorbent dose was evaluated in the range of 0.2–5.0 g L^{-1} at a fixed contact time of 60 min. The adsorption capacity and removal degree were used to assess adsorption efficiency. The results demonstrated a strong dependence of CR removal on both contact time and adsorbent dose. Rapid CR uptake occurred during the initial stages of adsorption for both samples, followed by a slower approach to equilibrium. Kinetic data were successfully described using pseudo-first-order and pseudo-second-order models, with the latter providing a better fit. Due to its higher surfactant content, P2 showed enhanced adsorption capacity (26.8 mg g^{-1}) and faster kinetics compared to P1 (18.6 mg g^{-1}), confirming that surfactant molecules serve as the active sites for CR adsorption. Additionally, increasing the adsorbent dose led to an increase in CR removal efficiency for both samples. Overall, cetylpyridinium-modified phillipsite, particularly P2, showed potential for efficient removal of anionic dyes from aqueous media, highlighting its applicability in wastewater treatment processes.

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Utilization of Immobilized Peroxidase for Phenolic Compounds Removal from Water

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Phenol and its derivatives can be found as pollutants in wastewater from various industries in a wide range of concentrations. The presence of these organic pollutants in water poses a potential risk to the environment and human health. The application of conventional wastewater treatments achieves only a certain degree of water purification, so new alternative technologies are being developed for the treatment of phenol-containing wastewater. Processes that can effectively remove phenolic components from wastewater are biocatalytic processes based on the use of enzymes such as peroxidases. Peroxidases are enzymes that are often used in wastewater treatment due to its ability to oxidize a wide range of organic compounds, including phenols. In the water treatment process, enzymes can be used in free and immobilized form. Immobilization of enzymes on a carrier (e.g. metal oxide, polymer, composite material) provides a stable biocatalyst with higher activity than the free enzyme and can be used repeatedly in repeated cycles. The selection of an appropriate carrier for enzyme immobilization is very important because it affects the enzyme loading, operational stability and overall process costs. In general, peroxidases immobilized onto magnetic solid supports show higher stability and reusability than immobilized onto non-magnetic carriers [1]. The application of peroxidases immobilized on various supports has shown high enzymatic biodegradation efficiency for the removal of various phenolic compounds from water, such as phenol and its derivatives, pharmaceuticals, endocrine-disrupting compounds, industrial dyes, and has great potential for real-world wastewater treatment.

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Fixed-Bed Removal of Crystal Violet Dye Using Activated Carbon Fibers: Experimental and Numerical Investigation

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The widespread use and improper disposal of crystal violet (CV) dye into aquatic ecosystems have raised serious environmental concerns. Developing efficient removal strategies to prevent CV's accumulation in water bodies is therefore essential. Activated carbons are widely used as highly effective adsorbents for treating contaminated water. Among various approaches, the fixed-bed adsorption method offers continuous operation and enables the treatment of large volumes of wastewater using a constant amount of adsorbent. This study investigates the use of oxidized activated carbon fibers (Felt-Ox) for efficient CV removal dye through the fixed-bed adsorption method. The performance of Felt-Ox was compared with three other activated carbon-based adsorbents (MSC-Ox, F400 and Luffa-Ox). The physicochemical properties of the adsorbents were systematically characterized by conducting gas sorption analysis, scanning electron microscopy, X-ray photoelectron spectroscopy and Fourier-transform infrared spectroscopy. The maximum CV adsorption capacity of the adsorbents was quantitively evaluated by fitting the experimental breakthrough curves to the Yan model. Moreover, the effect of adsorbent mass on CV removal efficiency was also examined. The results revealed that the Felt-Ox material exhibited the highest maximum adsorption capacity (19.6 mg/g) among all tested adsorbents. Additionally, to gain deeper insights into the hydrodynamics within the fixed-bed column and to evaluate the influence of key operational parameters, including flow rate and inlet concentration, a computational fluid dynamics model was developed and applied to analyze the adsorption performance.

MXene Photocatalysts for Emerging Water Pollutants Abatement

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Environmental problems associated with water pollution have raised serious concerns. Water contaminants of emerging concerns pose significant environmental and public health challenges due to their persistence and toxicity in aquatic systems. In this context, photocatalytic processes have been studied and were proven to be promising and environmentally friendly methods for water treatment. In this study, MXene synthesis was explored using Ti_3AlC_2 (MAX phase) as the precursor via a conventional chemical etching process with hydrofluoric acid (Alhabeb et al., 2017). Heterojunctions were also introduced using hydrothermal and precipitation synthesis techniques. The heterojunctions were prepared coupling MXene with ZnO and CeO_2. The photocatalytic activity of the developed materials was assessed by using the following model compounds: antibiotic sulfamethoxazole (SMX) and phenol, persistent contaminants poorly eliminated by conventional wastewater treatments. Under simulated irradiation ($\lambda > 340$ nm) and among the tested photocatalysts, MXene-ZnO-CeO_2 was the fastest in degrading both SMX and phenol (pollutant 10 mg L-1; catalyst 200 mg L-1), reaching full degradation in less than 2 hours for both pollutants. MXene-derived photocatalysts exhibited efficient photodegradation, achieving high removal efficiencies due to their excellent electrical conductivity, large surface area, and the ability to facilitate charge separation, which render them as attractive candidates for photocatalytic removal of pollutants as well as improvement of photocatalytic performance of semiconductor catalysts (Iravani & Varma, 2022). These findings highlight the potential of MXene-based photocatalysts in addressing recalcitrant organic contaminants in wastewater treatment applications.

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Synthesis of chitosan-carboxymethyl cellulose reinforced with activated carbon aerogel for efficient Cr(VI) removal

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Water quality is constantly threatened worldwide due to the discharge of heavy metals into water bodies from industrial waste. In particular, the anionic heavy metal hexavalent chromium (Cr(VI)) is widely present in wastewaters and poses carcinogenic and genotoxic risks to human health. Therefore, the effective treatment of chromium-containing wastewater using advanced materials or technologies is highly desirable. Among the existing and implemented techniques, adsorption remains one of the most popular approaches for treating chromium-containing wastewater, due to its simple technology, low cost, high efficiency, and reduced risk of secondary pollution. In this work, sustainable biopolymer aerogels based on chitosan (CS) combined with carboxymethyl cellulose (CMC) were successfully reinforced with bio-derived additives including activated carbon (AC) to develop high-performance green sorbents. FTIR analysis confirmed effective crosslinking, with glutaraldehyde (GLA) forming Schiff base (C=N) linkages via amino groups, resulting in a more compact network. Additionally, all aerogels exhibited predominantly amorphous structures, as confirmed by XRD analysis. SEM images exhibited hierarchical porous architectures, and the highest porosity was observed for CS/CMC/AC0.5-GLA (96.35%), while increased crosslinking reduced pore size to ~60% in CS/CMC/AC2-GLA. Exceptional water sorption was achieved for CS/CMC/AC0.5-GLA (3440.8% at 10 min), attributed to multiscale porosity and heteroatom-rich AC surfaces. According to the adsorption results, the optimal pH value was found to be 3.0; as the pH increases, the removal rate decreases, indicating chemisorption. The isothermal data were best fitted to the Langmuir model, suggesting monolayer adsorption, resulting in the CS/CMC/AC/MgO-GLA achieving an adsorption capacity of 155.53 mg/g after 24 hours of contact time and a dose of 0.5 g/L. Overall, bio-additive incorporation, highly porous, aerogels with enhanced water sorption capacity were synthesized for sustainable Cr(VI) sorption applications.

MICROPLASTICS IN THE ENVIRONMENT

Tracing microplastic pathways in wastewater treatment

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Growing water scarcity and the increasing reliance on wastewater reclamation have positioned wastewater treatment plants (WWTPs) as critical control points for both water quality protection and contaminant dissemination. Among emerging contaminants, microplastics (MPs) have attracted significant attention due to their ubiquity, environmental persistence, and potential risks to ecosystems and human health. WWTPs play a dual role in this context: while they act as effective sinks for MPs, they may also facilitate their redistribution through reclaimed water and sewage sludge reuse.

This keynote lecture addresses the occurrence, fate, and transfer pathways of MPs within wastewater treatment systems, with particular emphasis on advanced treatment technologies. Long-term monitoring data are presented to elucidate variations in MP concentrations, characteristics, and removal efficiencies across successive treatment stages in a full-scale municipal WWTP incorporating membrane bioreactor (MBR) technology and electrodialysis reversal (EDR) for water reclamation. These data provide insights into the effectiveness and limitations of state-of-the-art processes in mitigating MP emissions.

In parallel, the partitioning of MPs into solid waste streams was investigated through the analysis of sewage sludge fractions with different moisture contents over an annual cycle, allowing assessment of MPs accumulation and retention in residual matrices destined for land application.

MP analysis was performed using harmonized analytical workflows combining chemical digestion, density separation, and membrane filtration, followed by visual sorting under stereomicroscopy and polymer identification by micro-Fourier Transform Infrared (μ-FTIR) spectroscopy. The results contribute to a more comprehensive understanding of MP pathways in wastewater treatment and underscore the need to integrate MP monitoring into water reuse and sludge management strategies to minimize their environmental release.

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Microplastics Pollution: A growing threat – Health Risks, Environmental Concerns & a Call for Solutions

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The widespread use and persistence of synthetic plastics, combined with inadequate waste management, have led to the accumulation of plastic debris across different environments. Environmental exposure to factors such as UV irradiation, oxidation, mechanical abrasion, and biological activity progressively break down plastic materials into microplastics (MPs; <5 mm), which are now recognized as pollutants of global concern. MPs exhibit complex environmental behavior and have been associated with adverse biological effects, including oxidative stress, genotoxicity, metabolic disruption, and impaired growth in a wide range of organisms. Despite advances in analytical techniques, critical knowledge gaps still remain regarding the effects of natural weathering on polymer properties and the resulting biological impacts. This work provides an integrated overview of ongoing research on the environmental transformation of synthetic polymers and the biological effects of both pristine and environmentally aged MPs. UV-induced aging was applied to common polymers, including polyolefins and polyesters, to simulate realistic environmental conditions. Structural and physicochemical changes were assessed using FTIR, DSC, XRD, SEM, and Py-GC/MS, revealing extensive oxidation, changes in crystallinity, and shifts in pyrolytic markers that provide insight into degradation pathways and analytical challenges in MP identification. Moreover, ecotoxicological studies using *Danio rerio*, *Perca fluviatilis*, and *Cornu aspersum* demonstrated that MP characteristics, particularly particle size and oxidative state, strongly influence biological responses, with smaller and aged particles showing increased bioactivity. Overall, the findings highlight the critical link between polymer structure, environmental degradation, and biological impact, emphasizing the need for sustainability-oriented approaches to MP pollution in water, wastewater, and sludge management systems.

Sustainable bio-strategies for addressing wastewater treatment for the removal of organic contaminants and microplastics

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Microplastics (MPs) are formed through the decomposition of plastics by physical or chemical factors, such as action of waves, sunlight and oxygen. Wastewater MPs enter sewage systems, evade treatment, and together with ghost fishing nets, mostly made of nylon-6 and aquaculture gear pollute aquatic ecosystems. MPs act as carriers for harmful pollutants including pathogens and endocrine disrupting chemicals (EDCs). EDCs have been linked to the declining numbers of fish stocks and their diseases posing risks to humans, as end consumers. The EDC Bisphenol-A (BPA) is adsorbed and leaks from MPs, accumulating in sediments or in wildlife. Our preliminary data showed that uptake of BPA on nylon-6 fibers presented a threefold increase in seawater compared to tap water (1). A sustainable environmentally friendly alternative for plastic waste management is bioremediation by soil and water microbes. Probiotic bacteria biodegrade BPA to harmless end products (2) and enhance its biotransformation by the live fish feed Artemia (3). The edible insect *Tenebrio molitor* (mealworm) has been employed in bioremediation due to its ability to consume MPs through its gut microbiota, converting them into biomass. Our preliminary results showed that mealworm larvae can degrade nylon-6 fibers and are resistant to BPA, removing it from their feeding substrate at the cost of reversible oxidative stress. Hence, probiotics and their combination with plastic-degrading bacteria isolated from mealworm guts might serve as a future bioremediation solution.

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Microplastic Pollution in Greek Seas: Study of post-storm effects, spatio-temporal analysis and abundance in Greek Seas.

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In the context of the Typhoon Microplastic Project, seawater and sediment sampling was carried out in 27 coastal areas of Greece between 2021 and 2024. The collected samples were analyzed to assess the presence of potential microplastics. The extracted particles were subsequently identified using FT-IR spectroscopy and categorized according to their shape and color Distinct differences were observed between the two matrices. Spatio-temporal analyses showed a seasonality pattern with increased abundance during months with great rainfall (end of winter – early spring), while a pattern of concentration of microplastic fragments was observed in the southern Aegean Sea, in the Dodecanese islands. Fragments and films were the most common shapes of microplastics, especially in heavily polluted areas, such as Thermaikos and Pagasitikos Gulf. The most common polymers in both matrices were polypropylene (PP) and poly(ethylene) (PE), followed by polystyrene (PS). In the context of the study, the post-storm effects of the Medicane "Daniel" were studied regarding its influence on the abundance of microplastics in the Pagasitikos and Thermaikos Gulf. With the use of satellite-derived SPM (Suspended Particulate Matter) data and the results of the abundance of microplastics, a positive correlation was observed between these values, showing that storm-driven runoffs and the hydrodynamic conditions of an area can greatly contribute to the transfer of land-originated microplastics to coastal areas (Estahbanati & Fahrenfeld, 2016; Veerasingam et al., 2016). Finally, the potential sources of microplastics were studied in Thermaikos and Pagasitikos Gulf in comparison with the already existing bibliography and mapping of population, anthropogenic activities and wastewater plants in the areas (Kalaronis et al., 2025).

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Mass-Based Semi-Quantitative Assessment of Microplastics/Nanoplastics in Aquatic Environmental Matrices

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Microplastics (MPs; <5 mm) and nanoplastics (NPs; typically <1 μm) have been widely detected across environmental compartments, including marine and freshwater systems, sediments, soils, and biota. Owing to their small dimensions, limited capture efficiency, and the difficulty of isolating them from complex matrices, these small-sized particles are characterized nowadays as a growing global concern. Reliable assessment of their occurrence requires robust analytical methods capable of determining both polymer identity and particle abundance. In recent years, several approaches have been proposed to characterize MPs and NPs; among them, pyrolysis coupled with gas chromatography–mass spectrometry (Py–GC/MS) has gained increasing attention, due to its ability to chemically identify polymers and quantify them on a mass basis through chromatographic separation and mass spectral confirmation. Herein, a Py–GC/MS-based analytical workflow was developed for the identification and quantification of MPs in real environmental samples. A polymer reference mixture comprising nine commercially relevant plastics was prepared, and polymer-specific calibration curves were established. The influence of $CaCO_3$ as a catalyst was also investigated to enhance the stability of reactive degradation products in mixed-polymer systems. Chromatographic data were processed using F-Search software to enable rapid comparison with reference spectral libraries. The validated methodology was applied to seawater, river, and wastewater samples in two sampling periods (late 2023 and spring 2024), demonstrating rapid screening and quantification of the polymers present. Although the current study focuses on MPs, work is underway to extend the framework from MPs to NP characterization, which remains a key analytical challenge.

Acknowledgement

The methodology for the identification and determination of polymers by Py–GC/MS was supported by the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 101057285 (SPECTRA Project).

From Pollution to Solution: Transforming Nylon Microplastics into Magnetic Sorbents for Radionuclide Removal and Antibacterial Activity

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(Micro)plastics (MPs) are a critical and persistent global pollutant, raising growing concern not only as contaminants themselves but also as secondary pollutants that act as carriers for other contaminants. This work presents an environmentally friendly strategy to convert MPs from hazardous waste into value-added functional materials for water remediation. Specifically, polyamide (PA6) microplastics were functionalized with Fe(II,III) oxide nanoparticles (FeNPs) to produce magnetic hybrid sorbents capable of removing ultra-trace concentrations of uranium and americium from real seawater.

FeNP incorporation imparted magnetic separability, enabling facile recovery and reuse, while also providing antibacterial functionality essential for aquatic applications. SEM and XRD analyses confirmed homogeneous decoration of approximately half of the MP surface by FeNPs (150–290 nm), forming a uniform monolayer and verifying nanoparticle dispersion and crystallinity. FTIR and thermal analyses evidenced chemical interactions between FeNPs and nylon functional groups, together with increased hydrophobicity and thermal stability. Elemental analysis indicated a FeNP loading of 34.2 wt.%, confirming the high degree of nanoparticle incorporation.

Compared with pristine MPs, the hybrid material showed substantially enhanced radionuclide uptake (44% for U and 78% for Am) and strong bactericidal activity against *E. coli*. Beyond advancing remediation technologies, this work demonstrates a circular innovation concept by transforming persistent plastic pollutants into functional remediation media. The approach enables scalable applications in nuclear waste management, seawater decontamination, and wastewater treatment, while directly supporting European priorities related to the Green Deal towards the circular economy.

SUSTAINABILITY AND LIFE CYCLE THINKING

Greenness and Sustainability in Analytical Chemistry: From Concepts to Practice

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The pursuit of green and sustainable practices has become a cornerstone of modern analytical chemistry, prompting a fundamental reevaluation of analytical workflows. This talk will highlight recent advances in green analytical chemistry, including the introduction of the Green Sample Preparation [1] and Circular Analytical Chemistry [2] concepts, the development of AGREEprep metric [3], and the more recent GreenSOL [4] solvent selection guide tailored to analytical chemistry. Sustainable Analytical Chemistry will be framed through its three interdependent pillars, environmental, societal, and economic, advocating for systems thinking [5]. Building on this foundation, the presentation will explore in detail current perceptions of sustainability in the analytical chemistry community, highlighting the gap between partial compliance with green criteria and the systemic transformation required for genuine sustainability. By identifying key areas for improvement and offering actionable recommendations, this contribution advocates a paradigm shift in analytical chemistry, moving beyond incremental technical improvements toward systemic change.

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Adsorption-Based Metal Recovery: One Step Closer to Effective Lithium-ion Batteries Recycling

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The improper disposal of Lithium-ion batteries represents a major threat for the environment and public health due to the contamination of water courses and heavy metals bioaccumulation. [1] On the other hand, the actual recycling methods for the aforementioned batteries are neither effective, nor economically viable to be considered as a suitable option for the recovery of metals such as Lithium, Nickel and Cobalt. [2], [3] A promising and environmentally friendly alternative to address this issue and mitigate the adverse effects of mining involves the repurposing of aluminosilicate materials, derived from the prospection and processing of lithium-containing minerals. These materials possess relevant adsorption properties, which can be further enhanced through surface modifications to improve both adsorption capacity and selectivity towards specific metal ions. In this context, bentonite clay was subjected to various surface modifications, including the incorporation of nitrogen-containing functional groups, treatment with acidic and basic precursors, and the development of composites with activated carbon. The modified materials were tested using aqueous solutions of nickel and cobalt, as well as mixed-metal systems. Adsorption kinetics revealed an equilibrium time of approximately 24 hours. It was shown that the presence of nitrogen groups enhances the adsorption ability of bentonite. These materials have shown selectivity towards nickel. The introduction of nitrogen groups resulted in an increase in adsorption capacity, and the best adsorption behavior was shown at higher pH values. Desorption studies employing various eluents indicated that the most effective desorbing solution was 0.1 M sodium chloride at pH 1, achieving a desorption efficiency of 47%. These findings highlight the potential of surface-engineered bentonite as a cost-effective and sustainable material for selective metal recovery from lithium-ion battery leachates.

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Ensuring safe irrigation water for agricultural use via quaternary wastewater treatment

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Human activities have a profound impact on the environment, contributing to challenges such as a loss of biodiversity and water scarcity, often manifested as increased water stress. One promising approach to address these issues is the reuse of treated wastewater (TWW) for agricultural irrigation. However, the application of TWW on crops raises concerns regarding soil quality, crop health, and consumer safety. This study investigated a quaternary treatment (QT) being applied at the wastewater treatment plant (WWTP) in Trnava – Zeleneč (Slovakia). The aim of this project was to produce TWW that is chemically and microbiologically safe for irrigation, while monitoring the quality of produced water, crops and soil. Various agricultural crops, including onions (Crockett), potatoes (Laura), carrots (Romance), and parsley (Efez), were cultivated using the quaternary TWW. The treatment process incorporated advanced methods such as coagulation, ultrafiltration, adsorption, and disinfection by UV lamp to improve water quality. The results showed a substantial improvement in quality of WWTP effluent, indicating its suitability for agricultural use. The median value of COD removal efficiency was 33%, which confirms the potential of QT to further reduce organic pollution in the WWTP effluent. Furthermore, total nitrogen (TN) concentrations fluctuated in both effluents, while ammonium ion nitrogen ($N-NH_4^+$) remained below 1 mg/L in all instances, and nitrate nitrogen ($N-NO_3^-$) exhibited a subtle declining trend throughout the run time of the QT. Additionally, removal efficiency of total phosphorus (TP) ranged from 70% to 82%, which is typical for water treatment technologies containing coagulation. With great expectations, significant removal efficiencies were also observed for heavy metals as well, specifically for Cu, Zn, and Ni were reduced by 70%, 50%, and 20% respectively. Finally, soil and crops quality was analyzed as well, with the concentrations of pesticides and heavy metals not exceeding any allowed limits, and moreover, the experimental soil and crops usually contained less pesticides and heavy metals than their reference counterpart.

Acknowledgement

This work was supported by the Research and Development Agency under Contract No. APVV−22−0292.

Fostering sustainability with innovative solutions: A knowledge-driven tool for circularity

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Evolving sustainability regulations and ESG standards compel businesses to adapt, replacing optional practices. However, SMEs face challenges transitioning their operations to meet current legislative targets (Wojtaszek et al., 2025). Bridging the gap between ESG assessment and the adoption of circular innovations, this work establishes a robust framework for corporate sustainability by mapping standards (e.g., ESRS, ISO 59020) against specific ESG indicators. To further promote sustainability, a repository of circular economy innovations was developed. A series of best practices and innovations were identified and classified based on their applicability to specific categories (e.g., NACE codes, Technology Readiness Level, environmental sector). Information is a structured, machine readable and human auditable mapping, using a Knowledge Graph standard, ESG indicators, evidence, and circular innovations (classified by NACE, TRL, sector). grounded decision support GenAI workflows suggest innovation pathways while preserving traceability

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Assessment of Novel Circularity Indicators for Biobased Feedstocks Valorization:: A Biofertilizer Production Case Study in Central Macedonia, Greece

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The transition towards circular and resilient agri-food systems requires harmonized indicators capable of capturing material, energy, and water flows across complex value chains. This study applies a comprehensive set of circularity indicators to a biofertilizer production value chain in the Region of Central Macedonia (Greece), integrating primary agriculture, food processing, and organic waste (i.e. tree pruning, straw and peach pulp/sludge) valorisation, building on recent advances in systematic circularity assessment methodologies (Renfrew et al., 2024). The analyzed value chain includes wheat and peach producers, a peach canning industry, and a composting facility. Circularity indicators were calculated using a harmonized framework, with emphasis on sustainably renewable production, residue avoidability, and sustainable residue removal rates.

Results indicate moderate circular content for agricultural residues (55–57%), influenced by organic farming shares and residue management pathways. While utilization rates exceed 80% at the primary production stage, value-based utilization is lower, reflecting downcycling and energy recovery pathways. Biofertilizer production achieves a circular content of 50%, combining primary and pre-consumer residues, alongside high production efficiency (86%) and favorable energy intensity.

Overall, the study demonstrates the added value of integrating mass- and value-based circularity indicators and supports their use as decision-support tools to enhance circularity, sustainability, and resilience in value chains for the valorization of agri-food wastes and by-products.

Acknowledgements:

This study was implemented in the context of BioReCer project funded from the Horizon Europe framework program (Grant Agreement No.101060684).

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Thermal Desorption Unit (TDU) – Antipollution Ritsona Facility

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Antipollution, a member of V Group, specializes in integrated waste management and circular economy solutions, providing sustainable services across land and sea operations. Within this framework, the company has invested in a Thermal Desorption Unit (TDU), which is installed and fully operational at its licensed hazardous waste management facility in Ritsona, Chalkida.

Thermal desorption is a controlled physical separation process in which contaminated soil or sludge is indirectly heated under negative pressure to volatilize selected pollutants without combustion. The process operates in a closed system and includes vapor collection, condensation, and off-gas treatment through activated carbon filtration to ensure compliance with environmental standards. The technology is suitable for the treatment of petroleum-contaminated sludges, refinery and drilling wastes, mercury-contaminated materials, hydrocarbon-contaminated soils (e.g., TPH, PAHs, PCBs), and other volatile or semi-volatile organic contaminants. During treatment, contaminants are separated into distinct fractions. Recovered hydrocarbons may be further utilized or managed according to their characteristics, elemental mercury is safely separated and managed in accordance with regulatory requirements, treated soil is rendered suitable for further use or downstream processing, and recovered water is treated and reused within the process or managed appropriately depending on its quality. This presentation outlines the Thermal Desorption process through selected waste treatment case examples.

Surface Water Quality Response to Dam Construction: The Pchelina Dam, Bulgaria Study

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The upper Struma River in Bulgaria has experienced long-term anthropogenic pressure from the industrial zones of Pernik and Radomir, resulting in substantial changes in pollutant loads over recent decades. The Pchelina Dam, constructed in the 1970s, was intended to mitigate downstream pollution through sediment retention.

This study assesses the influence of the Pchelina Dam on surface water quality in the upper Struma River basin based on a one-year monitoring campaign (May 2024–April 2025). Monthly water samples were collected from ten sites and analyzed for 35 parameters, including physicochemical indicators, nutrients, potentially toxic elements (PTEs), and α- and β-radioactivity.

Partial Least Squares–Discriminant Analysis (PLS-DA) revealed clear spatial differentiation of samples into four groups—upstream Struma River, Svetlia River, Pchelina Dam, and downstream section—with good to excellent classification performance (AUC > 0.8). Upstream samples were characterized by elevated electrical conductivity, nutrients, sulfate, β-radioactivity, and increased concentrations of Al, V, Co, Ni, Zn, As, and U. Samples from the Pchelina Dam showed an intermediate chemical signature, marked by higher chemical oxygen demand and lower total carbon compared to riverine sites.

The results demonstrate that the Pchelina Dam significantly alters the longitudinal water quality profile of the upper Struma River by retaining nutrients and PTEs, highlighting its role in regulating downstream water quality.

Acknowledgment:

The authors acknowledge the financial support by the Bulgarian National Science Fund Project КП-06-Н79/3 "Development of integrated methodology for dams' chemical impact assessment on adjacent surface water bodies (DIMDAMS)".

Callinectes sapidus waste valorization: Extraction and quantification of carotenoids and total phenolics from blue crab shell

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Callinectes sapidus (Rathbun), commonly known as the blue crab, is a highly invasive species listed among the 100 worst global invaders (Lowe et al., 2000). Native to the western Atlantic, it colonised the Mediterranean and Black Sea in the mid-20th century via uncertain pathways, where it now poses significant ecological and management challenges requiring coordinated and costly control measures (Kampouris et al., 2020). While stakeholders remain divided between emerging economic opportunities and ecological impacts driven by its aggressive predation and rapid population growth, increasing attention has focused on biomass valorisation (Nardelli et al., 2024). In particular, crab shells that constitute approximately 84-91% of the crab's raw biomass are typically discarded as waste despite being rich in bioactive compounds such as carotenoids, chitin, chitosan and peptides. These compounds have potential applications in pharmaceuticals, nutraceuticals, cosmetics, enzyme production and poultry feed supplementation (Antunes-Valcareggi et al., 2017). Based on circular economy principles, this study investigated the extraction and quantification of carotenoids, particularly astaxanthin, and total phenolic content (TPC) from blue crab shells. Shells obtained from a seafood processing facility were either steam-boiled to simulate industrial processing or left raw, then dried at 60 °C for 16 h, pulverised and extracted using an ultrasonic bath with various solvents. From preliminary screening, ethanol-water (80:20, v/v) was identified as the most effective solvent and extraction parameters were optimized using a central composite design (CCD) within a response surface methodology (RSM) framework (Al-idee T., et al., 2020; Yuan Y., et al., 2008). Total carotenoids, astaxanthin and TPC were selected as response variables, with astaxanthin quantified by HPLC, total carotenoids by spectrophotometry at 473 nm and TPC by the Folin-Ciocalteu method (Lamuela-Raventós, R. M., 2018). Raw shells exhibited higher carotenoid concentrations than pre-treated material, likely due to partial thermal degradation of heat-sensitive carotenoids. These findings support the potential of blue crab waste as a focus for further research directed towards its effective exploitation in functional product development, thus promoting sustainable population management and value-added applications.

Funding:

This research has been conducted in the frame of "Clusters of Research Excellence 1247 (CREs)" 2024 – 2026 («CrubShellUse: Sustainable utilization of shellfish and crustacean shells with the aim of developing innovative food ingredients and improving animal welfare, through their addition to diets», action code: YΠ3TA0560365) that was co-financed by National Hellenic Funds and the European Union (European Regional Development Fund).

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SUSTAINABILITY IN AQUACULTURE

When a species disappears: Ancient and modern DNA insights into the evolutionary history of *Pinna nobilis*, its mass mortality, and the expansion of *Pinna rudis*.

Daria Sanna

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The Mediterranean endemic bivalve *Pinna nobilis*, a key ecosystem engineer, is currently on the brink of extinction due to a devastating Mass Mortality Event (MME) [1] that began in 2016. This study reconstructs the evolutionary history and genetic resilience of the species by integrating data from ancient, historical, and modern DNA. By analyzing mitochondrial COI gene sequences from samples dating as far back as the 18th century, we have traced the origin of *P. nobilis* lineages to a divergence from an Atlantic ancestor approximately 2.5 million years ago (mya) [2]. Our findings reveal a complex evolutionary path characterized by an early settlement in the Western Mediterranean, followed by a Pleistocene radiation (1.5 mya) that expanded into the Adriatic and Eastern basins.

Despite the catastrophic impact of the MME, which led to a dramatic population collapse, our analysis of survivors shows that a significant portion of the species' historical (and adaptative) genetic diversity has been preserved [3]. This suggests a potential for resilience rooted in its long evolutionary history. However, as *P. nobilis* populations vanish from their traditional habitats, a significant ecological shift is being observed with the rapid expansion of *Pinna rudis* into the ecological niches left vacant by *P. nobilis*. Indeed, unlike its larger relative, *P. rudis* appears unaffected by the current MME pathogens, allowing it to colonize depths and areas where it was previously less dominant.

To better understand the dynamics of the genus under environmental pressure, we expanded our genetic investigation to *P. rudis*. Through the analysis of two mitochondrial markers (COI and 16S) across Atlantic and Mediterranean populations, we found that although *P. rudis* currently represents a single species, gene flow between these two basins has been interrupted, leading to the onset of a genetic divergence. Our results indicate that the Atlantic population originated approximately one million years ago and is currently stable and highly variable. In contrast, the Mediterranean population is slightly more recent, likely originating from Atlantic individuals that entered the basin. Interestingly, while *P. nobilis* faces a dramatic decline, accompanied by the loss of a fraction of the genetic variability present before the MME, *P. rudis* populations in the Mediterranean appear to be in a phase of expansion. This finding could be a possible consequence of the occupation of the ecological niches left vacant by the noble pen shell.

In conclusion, our studies provide a comprehensive temporal perspective on the genetic health of P. nobilis while highlighting the shifting ecological landscape of the Mediterranean. Understanding the competitive dynamics and the expansion of P. rudis is essential for developing sustainable management strategies in a rapidly changing Mediterranean. These findings offer vital baseline data for European restoration projects like LIFE PINNA, ensuring that conservation and management strategies are informed by both past evolutionary signals and current population dynamics.

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Reframing Invasive Alien Species: Use-Based Management as a Strategy for Ecosystem Restoration

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The Mediterranean Sea, one of the basins most affected (Myers et al. 2000), has been under the intense pressure of invasive alien species (IAS) (Zenetos et al. 2010; Gonulal et al. 2024). Various methods are proposed and implemented to combat these species. Since these methods vary according to species characteristics and habitats, it is important to adopt distinct approaches for each species and area. While preventing the introduction of IAS into an environment remains the most critical management strategy, factors such as a anthropogenic activities, and climate change facilitate their spread to diverse habitats. Once an invasive species has established itself in an ecosystem, eradication is the most common management tool. To make this method effective, it is vital to assign economic value to the removed species (Kuruoglu et al., 2025). In particular, promoting the consumption of edible invasive species by introducing them to local communities not only reduces predatory pressure on native species but also ensures the removal of IAS from the environment through consumption.

In Turkiye, extensive studies are underway to integrate species that cause significant economic and ecological damage—particularly to fisheries and biodiversity—into the economy. Among these, edible species such as Pterois miles, Sargocentron rubrum, Saurida lessepsianus, Nemipterus randalli, Upeneus moluccensis, Siganus luridus, S. rivulatus, Fistularia commersoni, Diadema setosum, and Callinectes sapidus lead the way. Through the "New Fishes" project, communication between fishers and restaurants has been established, resulting in 20 tons of invasive alien fish being purchased from fishers and integrated into restaurant menus between 2021 and 2026. Furthermore, various festivals have been organized to raise awareness among the local population. Ultimately, this study demonstrates with concrete data how invasive species can be transformed from a mere threat into an effective management tool for ecosystem restoration through use-based strategies that benefit both biodiversity and the local economy.

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Circular Biovalorization of Dairy Wastewater through Microalgae: A Sustainable Route for Novel Dairy Products

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The transformation of dairy wastewater into value-added products represents a critical opportunity for advancing circular bioeconomy strategies in the agri-food sector. Cheese whey, one of the most abundant by products of dairy processing, contains high concentrations of organic nutrients, including lactose (~45 g/L), proteins (7.2 g/L), lipids (~0.5–1 g/L) and minerals, while exhibiting a high chemical oxygen demand (~57 g/L), highlighting both its environmental burden and its valorization potential. This work explores the conversion of whey into functional food ingredients through microalgal cultivation. Experiments with Arthrospira platensis, Chlorella vulgaris and Auxenochlorella protothecoides (5–40% whey) demonstrated increasing biomass productivity with higher whey concentrations. While A. platensis and C. vulgaris produced approximately 2–2.6 g/L biomass but were prone to microbial contamination, axenic cultures of A. protothecoides achieved higher productivity, reaching ~3.8 g/L and exceeding 5–6 g/L under glucose supplemented conditions. The produced biomass was successfully integrated into fermented dairy matrices, enhancing nutritional value and supporting improved probiotic stability. From a techno-economic perspective, the integration of microalgal cultivation into dairy processing offers a scalable waste-to-value strategy, simultaneously mitigating the environmental burden of high-strength whey effluents (COD ~57 g/L) while generating high-value biomass for functional food applications, thereby supporting the transition of the dairy sector towards economically viable circular bioeconomy models.

Keywords: Dairy waste valorization; microalgae biotechnology; functional bioresources; sustainable food systems; circular bioeconomy.

Prevention and mitigation of the plastic litter produced from mussel farm activities in Thermaikos Gulf: Solutions and obstacles.

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Thermaikos Gulf is the largest gulf in the Aegean Sea, where Thessaloniki, the second-largest city in Greece, is located. The Gulf hosts very important wetlands, including estuaries, salt marshes, lagoons, and the deltas of the rivers flowing into the Gulf, Axios, Loudias, Aliakmonas, and Gallikos, forming a significant delta that is part of the National Park of Axios Delta. Additionally, the area belongs to Natura2000 sites and is also protected by the Ramsar Convention. Despite its great importance and ecological value, the Thermaikos Gulf is heavily affected by anthropogenic activities, such as industrial development, agriculture, tourism, illegal activities and other activities. Thermaikos Gulf hosts the largest mussel production in Greece, but due to its intensive production and poor waste management, it is one of the major sources of pollution in the area. For many years, the plastic nets, cords and barrels were discarded in the Gulf after their use. In the context of iSea activities, a waste collection and management plan was built in collaboration with the local fishers' association, local authorities, and recycling companies. According to the plan, an area will be demarcated for the exclusive collection of plastic mussel nets and cords in order to be recycled, while there is interest for recycling companies in collecting plastic barrels. Until now, more than 33 tons of plastic mussel nets and cords and 100 barrels have been collected and recycled. To establish a well-structured plan, there are many obstacles, such as the necessary licenses to create the collection spot, informing and raising awareness among the mussel farmers for the spots, the collection of the damaged barrels, storing the waste, the standards followed by the recycling companies, etc.

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Sustainable aquaponic production of common carp (Cyprinus carpio) and lettuce (Lactuca sativa) using insect-based feeds and hydroponic by-products within a circular economy framework

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Aquaculture faces increasing constraints due to water scarcity, environmental pollution, and dependence on increasingly scarce feed ingredients. Aquaponics offers a sustainable and circular production strategy by integrating fish culture with hydroponic plant cultivation in closed-loop aquaponic (CLA) systems. Within these systems, synergistic interactions among fish, plants, and nitrifying microorganisms enable the bioconversion of fish metabolic wastes into plant-available nutrients. This process reduces nutrient discharge, freshwater consumption, and overall environmental impact.

Closed-loop aquaponic systems provide additional benefits through minimized water losses from evaporation, achieved by continuous water recirculation and limited exposure of open water surfaces. These characteristics enhance water-use efficiency and make CLA systems particularly suitable for regions experiencing freshwater scarcity, thereby supporting sustainable water management and climate change adaptation.

In this study, common carp (Cyprinus carpio), a widely cultured freshwater species with high tolerance to recirculating aquaculture systems, was co-cultivated with lettuce (Lactuca sativa) in a laboratory-scale CLA system. Insect-based feeds derived from Hermetia illucens, insect frass, and hydroponic by-products were evaluated as partial replacements for fishmeal. System functionality, production performance, and water-use efficiency were assessed within a circular economy framework. The results highlight the potential of insect-based aquaponic systems to enhance the sustainability of aquaculture production while reducing reliance on finite resources and mitigating environmental pollution.

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From Freshwater Pollution to the Food Web: Pollutants and Toxins in Freshwater Crayfish

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Freshwater ecosystems are exposed to a wide range of pollutants originating from industrial activities, agriculture, urban wastewater, and in-lake management practices. This contribution reviews current evidence on the sources, spatial patterns, and bioaccumulation of organic pollutants and toxins in freshwater crayfish, highlighting their value as bioindicators of aquatic contamination. Crayfish are shown to accumulate diverse contaminant groups, including heavy metals, persistent organic pollutants (POPs), pharmaceuticals, endocrine-disrupting compounds, microplastics, cyanotoxins, fluoride, rare earth elements, and radionuclides. Bioaccumulation patterns vary among tissues, with the hepatopancreas, muscle, gills, and exoskeleton portraying different exposure pathways and contaminant bioavailability. Case studies from rivers, lakes, reservoirs, and contaminated industrial sites demonstrate that pollutant concentrations are often linked to local anthropogenic pressures, sediment characteristics, and site-specific environmental conditions, rather than simple downstream gradients. In addition, some water management interventions, such as the application of lanthanum-modified clays for eutrophication control, may unintentionally increase contaminant exposure in crayfish. Given their benthic lifestyle, omnivorous feeding behavior, and ecological relevance, crayfish provide integrative information on chemical stressors in freshwater systems. Moreover, their widespread human consumption highlights the importance of crayfish-based monitoring for environmental risk assessment and food-safety evaluation. The findings support the inclusion of crayfish in integrated freshwater pollution monitoring frameworks and underscore the need to consider multiple contaminant sources and exposure routes when assessing ecosystem and human health risks.

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Genetic Markers of Thermal Resilience in Mussels of the Genus Mytilus: Implications for Sustainable Aquaculture

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Marine heatwaves are increasing in frequency and intensity due to global warming and severely impact coastal marine ecosystems. Elevated seawater temperatures trigger significant bivalve mortalities in aquaculture farms and natural fisheries. The Mediterranean mussel (*Mytilus galloprovincialis*) has suffered repeated mass mortality events due to temperature extremes in recent years. Such events may act as strong selective pressures, favoring genotypes of increased tolerance to thermal stress. In this study, we investigated whether the repeated temperature extremes have favored certain alleles at loci involved in oxidative stress response in *M. galloprovincialis*. We focused on two specific single nucleotide polymorphisms (SNPs) in the Cu-Zn superoxide dismutase (Cu-Zn sod) gene, previously identified to differ between resistant and susceptible to thermal stress individuals (Papadopoulos et al., 2025). Allele and genotype frequencies were compared among experimentally characterized resistant and susceptible mussels and field-collected individuals that survived a natural marine heatwave. Then, we compared the frequencies in natural populations from Greece, Iceland *(Mytilus edulis)*, and New Zealand representing contrasting thermal regimes. At the synonymous SNP cds-195, resistant and field-resistant animals showed similar frequencies of both alleles and genotypes, while both differed significantly from susceptible mussels. At the non-synonymous SNP cds-285, the G allele which is present in *mussel* populations from Greece and New Zealand was associated with increased thermal tolerance. For both loci, Greece and New Zealand populations showed similar allele and genotype distributions, whereas the M. edulis population from Iceland differed significantly from both. The results suggest that repeated temperature extremes may shape genetic variation at loci involved in thermal stress responses. These findings support a genetic basis for thermal resilience in the Mediterranean mussel and highlight the role of stress-responsive genes in adaptation to ongoing ocean warming, with direct implications for identifying heat-resilient stocks to enhance sustainability in mussel aquaculture.

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Microbiological indicators as preventive mechanisms of food safety in aquaculture and fisheries, a case model in Thermaikos Gulf, Greece

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Sustainable management of coastal waters requires monitoring systems capable of providing early indications of environmental pressures that may affect both ecosystem health and the safety of commercially important aquatic resources. In semi-enclosed and highly productive systems such as the Thermaikos Gulf, microbiological water quality assessment represents a critical component of early warning systems. The incorporation of microbiological indicators into preventive monitoring schemes can support timely management interventions, safeguard seafood quality, and enhance the sustainable exploitation of these key products of the Thermaikos Gulf. The aim of the present study is to assess the suitability of selected microbiological indicators as tools for early warning and preventive monitoring in coastal waters of the Thermaikos Gulf, with particular emphasis on their relevance to the sustainable management and safety of mussel and blue crab resources. Sampling was conducted in Thermaikos Gulf, including specimens obtained from a mussel farming unit as well as blue crabs collected using baited traps. In both cases, a total of 20 individuals per species were sampled and used for microbiological analysis. In mussels (Mytilus galloprovincialis), the digestive gland and mantle tissues, which constitute the edible parts of the species, were examined. In blue crabs (Callinectes sapidus), microbiological analyses focused on the digestive gland and white muscle tissue. Microbiological cultures were performed using both non-selective and selective media, aiming to detect bacterial taxa potentially posing risks to public health.

The microbiological cultures revealed the presence of several bacterial genera, including species with documented pathogenic potential for humans. Among these, bacteria belonging to the genus Vibrio were particularly prominent. The detection of such bacteria highlights the value of microbiological monitoring as an early warning tool for both ecosystem health and seafood safety.

Funding:

"Clusters of Research Excellence (CREs)" 2024 – 2026 («CrubShellUse: Sustainable utilization of shellfish and crustacean shells with the aim of developing innovative food ingredients and improving animal welfare, through their addition to diets», action code: ΥΠ3ΤΑ0560365) co-financed by National Greek Funds and the European Regional Development Fund).

Genetic Insights into the Endemic Ohrid Trout (Salmo letnica) in Lake Ohrid

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Ohrid trout (Salmo letnica) is a salmonid species endemic to Lake Ohrid, one of the most ancient and biodiverse ecosystems, located in the Albanian-North Macedonian border. The species comprises four described morphotypes (S. l. typicus, S. l. aestivalis, S. l. balcanicus, and S. l. lumi), primarily differentiated by morphological traits and reproductive behaviour [1,2]. Salmo letnica has historically played an important ecological and socio-economic role in Lake Ohrid, with artificial reproduction efforts implemented since the 1950s. However, increasing environmental and human pressures have caused significant population declines, with all morphotypes currently persisting at very low levels and potentially facing extinction risk [1,2]. Understanding the genetic structure of these morphological forms is essential both from an evolutionary perspective and for the development of sustainable aquaculture and targeted conservation actions. In the present study, the mitochondrial Control Region together with microsatellite marker were used to assess the genetic diversity and population structure among the four morphotypes. Samples were collected along the Albanian shoreline of Lake Ohrid, obtaining a total of 127 Control Region sequences (553 bp), which were analysed and compared with sequences from other Salmo species. Phylogenetic and clustering analyses revealed limited genetic differentiation among the four morphotypes, suggesting that their divergence may be primarily ecologically driven and not yet reflected at the mitochondrial level. Conversely, phylogenetic analyses including all Salmo species reported from the lake clearly distinguished S. letnica from S. ohridanus, confirming their genetic separation and supporting previous studies [3]. Moreover, mitochondrial findings support the hypothesis that S. letnica evolved within Lake Ohrid from ancestral S. farioides populations, with local environmental conditions shaping their phenotypic diversification. In parallel, 9 microsatellite loci were applied to the 127 individuals, revealing overall genetic homogeneity and gene flow among morphotypes, while also detecting an internal incipient fine-scale structuring between morphotype pairs. These outcomes highlight the importance of genetically informed management of endemic trout resources, particularly Salmo letnica, in the context of conservation-oriented aquaculture and restocking programs.

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From Invasive Species to Managed Resource: Genetic Insights into Callinectes sapidus in the Mediterranean basin.

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The Atlantic blue crab, Callinectes sapidus, is a widely recognized invasive alien species in the Mediterranean Sea, where it causes significant ecological and socio-economic impacts [1]. Given its extensive and well-established distribution across the basin, complete eradication is currently considered unfeasible. In this context, the continued expansion of Callinectes sapidus has direct and indirect effects on Mediterranean aquaculture, compromising the productivity of farming facilities through predation, damage to infrastructure, and alterations of benthic communities. As a result, several Mediterranean countries are exploring alternative management approaches aimed at mitigating its impacts while converting its presence into a potentially exploitable biological resource [2,3].

In this framework, a detailed understanding of the genetic structure and evolutionary history of Callinectes sapidus is essential to inform effective management and monitoring strategies. In the present study, we investigated the genetic variability and phylogeographic structure of Callinectes sapidus across its native and introduced ranges by analysing 667 mitochondrial Cytochrome c Oxidase subunit I (COI) sequences, including 36 newly generated sequences from under-investigated Mediterranean sites and 631 sequences retrieved from global populations. Phylogenetic and phylogeographic analyses identified two distinct but closely related genetic groups, suggesting the presence of a species complex composed of two putative sister species.

Mediterranean populations displayed a largely homogeneous mitochondrial pattern, consistent with recent and rapid colonization across most of the basin. Within this general framework, eastern Mediterranean populations, particularly those from Turkey, showed early signs of genetic differentiation, likely reflecting a longer establishment history and multiple introduction pathways. These results could provide a clear genetic baseline for distinguishing population units across the Mediterranean, which may be essential for stock identification. Overall, by improving our understanding of the evolutionary trajectories of Callinectes sapidus in the Mediterranean Sea, this study could offer a valuable foundation for the design of more effectively calibrated management and monitoring plans.

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The Role of Genetic Conservation in Sustainable Restocking and Fishery Resilience: The Case of Native Cyprinus carpio in Albania

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Inland fisheries and restocking play a crucial role in food security and socio-economic sustainability in Albania, where the common carp (Cyprinus carpio) remains one of the most important freshwater species. According to national statistics, a limited number of hatcheries in Albania produce about 0.8–1.6 million common carp fingerlings per year for restocking natural lakes, based on native broodstock, with the aim of maintaining common carp stocks in systems where the species is subject to intense fishing pressure. This study examines the role of genetic conservation in sustainable restocking and fishery resilience by integrating national catch statistics (2018–2024) with genetic and biological evidence from Albanian natural lakes and hatchery stocks. Inland catch data indicate that common carp contributes on average about 10–12% of total inland fisheries production, but with pronounced interannual fluctuations, including a marked increase in 2023 followed by a sharp decline in 2024, highlighting instability in stock performance. Microsatellite-based genetic studies of carp populations from Lake Shkodra, Lake Ohrid, and the Prespa Lakes reveal high allelic diversity and high expected heterozygosity, yet consistently lower observed heterozygosity, significant deviations from Hardy–Weinberg equilibrium, and low genetic differentiation among populations. These patterns point to heterozygote deficiency, inbreeding effects, and extensive anthropogenic gene flow associated with long-term restocking practices. Hatchery-based analyses further demonstrate that, despite high genetic variability, broodstock and fingerlings may still exhibit fixation and inbreeding signals, posing risks when used indiscriminately for stock enhancement. Overall, the findings show that restocking strategies focused primarily on increasing biomass can undermine the genetic integrity and long-term resilience of native carp populations. The Albanian case emphasizes the need for genetically informed restocking approaches based on the use of local broodstock, maintenance of effective population size, and routine genetic monitoring, as a prerequisite for sustainable inland fisheries management and the conservation of biodiversity.

Keywords: genetic conservation; sustainable restocking; microsatellite markers; genetic diversity; Albania

Environmental DNA as a Tool for Seasonal Detection of the Crayfish Plague Pathogen Aphanomyces astaci in lake Polifitou

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Aphanomyces astaci, the causative agent of crayfish plague, represents a major threat to indigenous crayfish populations across freshwater ecosystems (Lowe et al., 2000). In this study, we applied environmental DNA (eDNA) analysis to investigate the seasonal dynamics of A. astaci throughout an entire annual cycle in lake Polifitou, North Greece, after an epidemic outbreak, which devastated Pontastacus leptodactylus populations (Alvanou et al., 2024). In addition, DNA swab samples from asymptomatic *Pontastacus leptodactylus* individuals, and freshwater bivalves from each site were collected and analyzed. More specifically, bivalves from the lake were examined to assess their potential role as intermediate hosts contributing to the persistence and spread of the pathogen within crayfish populations. Three liters of water were collected monthly from each sampling point over twelve consecutive months and analyzed to detect pathogen presence from three different sampling points in the main crayfish farming areas in the lake. The results revealed clear seasonal variation in A. astaci eDNA presence. The pathogen was detected in water samples as well as in asymptomatic crayfish during February, March, and April, but was not detected in bivalves. Notably, the results indicate that *A. astaci* can persist in the environment even in the reduction of crayfish population, highlighting a potential long-term risk for crayfish population recovery. Following the peak during spring, A. astaci showed a decline in subsequent months, suggesting a reduction in pathogen abundance or activity. These patterns may be linked to seasonal changes in water temperature, host activity, and pathogen life-cycle dynamics. Our findings demonstrate that targeted eDNA analysis, rather than metagenomics, is a sensitive and effective tool for year-round monitoring of crayfish plague and for identifying periods of elevated infection risk. Seasonal surveillance using eDNA can support early warning and management strategies aimed at the conservation of vulnerable crayfish populations.

This research is supported by the Administrative Region of Western Macedonia, Greece (Region of Western Macedonia Protocol Number: 183267/13-11-2023, UOWM Special Account for Research and Funds Project Number: 81100).

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Wide-scope HRMS screening for emerging contaminants in aquaculture environments

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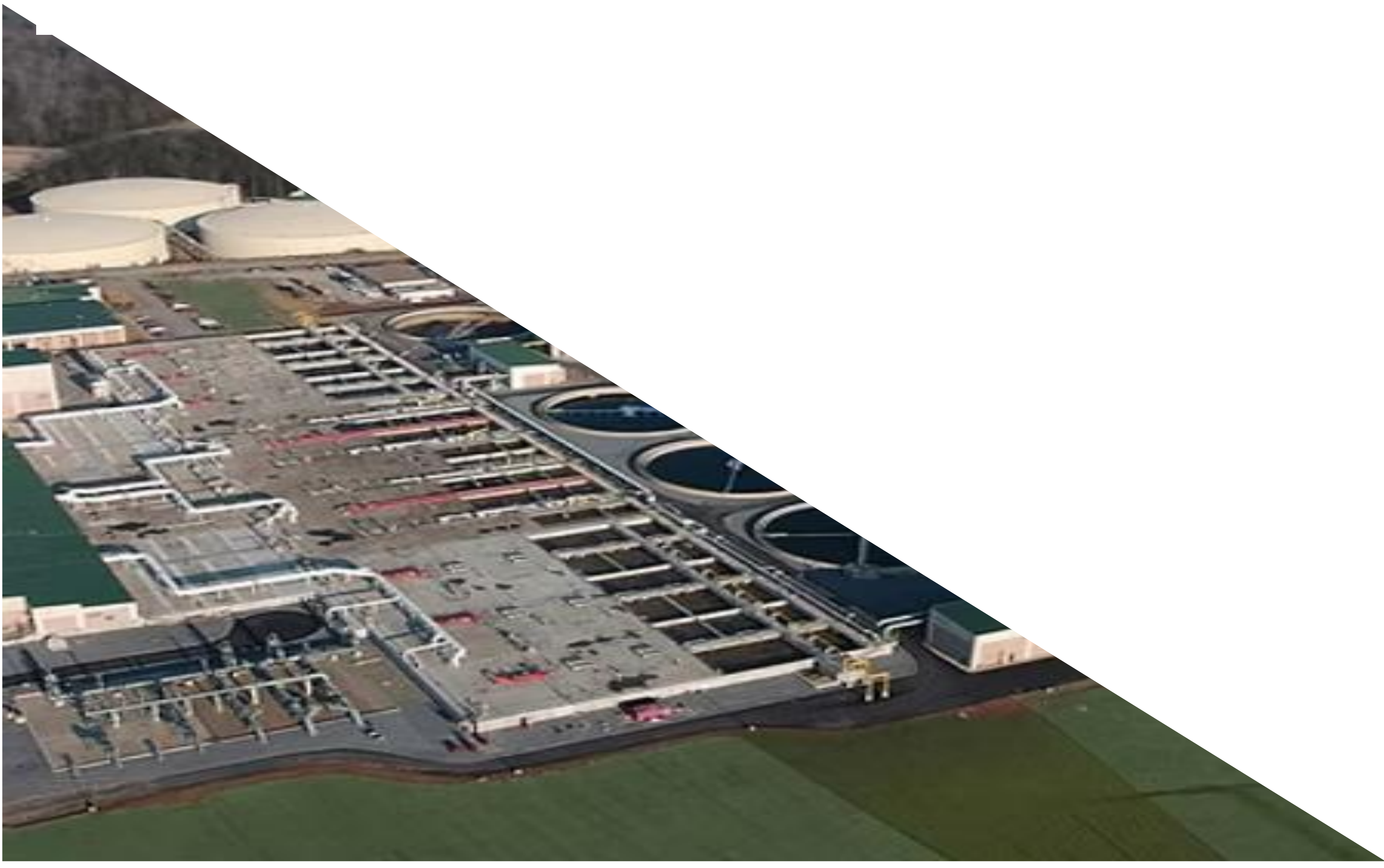
The occurrence of emerging contaminants in aquaculture systems poses a significant risk to food safety and human health, as these substances can bioaccumulate in filter-feeding organisms like mussels. The present study focuses on the determination of multiple classes of legacy and emerging contaminants, including pesticides, pharmaceuticals and personal care products (PPCPs), and per- and polyfluoroalkyl substances (PFAS), in aquaculture water samples, as well as PFAS in mussels. The samples were collected from mussel farms in Thermaikos Gulf in northern Greece. The presence and concentration levels of over 500 contaminants in aquaculture water were investigated through a consecutive 5-month monitoring period. Additionally, monitoring for PFAS was held in mussel samples over the course of 21 months. Sample preparation for aquaculture water was carried out by solid-phase extraction, while mussels were subjected to a modified QuEChERS extraction, followed by dispersive solid-phase cleanup. A highly sensitive analytical workflow that integrated target, suspect, and non-target analysis with extensive in-house databases was implemented for the analysis using liquid chromatography coupled to high-resolution mass spectrometry (LC-HRMS). Integrating target, suspect, and non-target workflows enabled wide-scope screening of emerging contaminants and expanded detection beyond conventional monitoring programs. An in-house mass spectral library was developed, alongside the assessment of peak picking, spectral deconvolution, and compound annotation. The most frequently detected contaminants in aquaculture water samples were caffeine, DEET, acetaminophen, atrazine, and nicotine. Among the PFAS analyzed in the mussel samples, PFOS was the most abundant and variable compound, whereas PFOA and PFNA were present at intermediate, relatively consistent levels. These findings highlight the need for comprehensive monitoring of emerging contaminants in aquaculture to ensure seafood safety and support environmental risk management and public health protection.

Funding:

The research project was supported by European Commission under the HORIZON-WIDERA- TWINNING BOTTOM-UP within the framework of the SPECTRA project (Grant No 101158453).

RESOURCES AND ENERGY RECOVERY



The importance of assessing environmental sustainability in circular economy projects

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The concept of sustainability can refer both to environmental aspects, economic issues and social acceptance. The environmental sustainability of an industrial chain is generally quantified using the Life Cycle Assessment (LCA). Although not yet widely adopted, this tool plays a significant role in circular economy projects, even at a laboratory scale, because it allows us to determine which phases have the greatest impact, thus maximizing sustainability in the event of a hypothetical upgrade. Two examples of LCA applications to material recovery projects will be presented. In the first case, the analysis was applied to a supply chain designed to recover the organic fraction of municipal solid waste using black soldier fly larvae to produce biofuel and bioplastics (RICH project) [1]. The assessment highlighted that currently, solutions conventionally used for the recovery of this type of waste have a lower impact in terms of CO_2 emissions than the proposed supply chain. In a second example, the analysis was applied to a chain designed to recover micro-PET and bioconvert it into high-value molecules, specifically amino acids (ProPla project) [2]. The results showed that both the extraction and bioconversion phases have the greatest impact. This work was supported by the Fondazione Cariplo grant "ProPla: proteins from plastics" 2022-0631.

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Nitrogen recovery from organic waste fermentation liquid for a novel waste-recycled chelating agent preparation

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Anaerobic fermentation liquid from food waste contains abundant nutrients, such as volatile fatty acids (VFAs) and NH3-N, which are promising nutrient sources for plant growth. Here, we report a novel integrated technique for the simultaneous recovery of C and N sources from anaerobic fermentation liquid. VFAs and NH3-N extracted from anaerobic fermentation liquid were synthesized and converted into layered double hydroxides (LDH) and NH4HCO3, respectively, for subsequent use as soil amendments to provide external C and N to plants. The X-ray diffraction, Fourier-transform infrared spectroscopy, and scanning electron microscopy/energy dispersive X-ray spectroscopy results suggested that VFAs were successfully intercalated within the LDH, and the composite (VFA-LDH) exhibited good sustained release performance. In the VFA-LDH synthesis process, the concentrations of chemical oxygen demand, VFAs, and NH3-N were reduced by 49.4%, 27.9%, and 43.6% in the anaerobic fermentation liquid, respectively. In addition, VFA-LDH and NH4HCO3 promoted increased soil fertility, including organic matter content, cation exchange capacity, and N and P contents. Overall, the developed technique exhibits great potential as an anaerobic fermentation liquid treatment and nutrient acquisition method.

From Regulations to Practice: Evaluating Barriers to Effective Nitrogen Management in Wastewater-Irrigated Olive Orchards in Cyprus

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Semi-arid countries, such as Cyprus, increasingly rely on the use of treated wastewater for irrigation, as contribution to the water balance. To prevent groundwater pollution, growers need to manage the complexity of variable irrigation water needs and waste water nutrient concentrations throughout the season. This study evaluates the practical implementation of the Code of Good Agricultural Practice for the Protection of Waters from Nitrate Pollution (K.D.P. 283/2023), which is part of the Water Pollution Control Laws of Cyprus. Interviews with 26 olive growers were conducted in the summer of 2026. While the Code requires the farmers to calculate the nitrogen (N) requirements for olive crops based on the concentration in the soil and the irrigation water - noting that official treatment plant analyses can be used - significant practical difficulties exist. However, water quality data from treatment plants on the websites of national authorities are difficult to find and not up to date. Furthermore, we found high monthly variability in the N content of the treated waste water, during the irrigation season. For instance, N concentrations of a rural treatment plant in 2023 more than doubled from 12.3 ppm in March to 25.7 ppm in August. From the 26 olive growers interviewed, 7 growers used treated waste water, but only one grower adjusted his practices by not adding supplemental N fertilizer. These findings highlight a critical gap between regulatory expectations and on-farm practices. It shows the need for accessible real-time data, user-friendly calculation tools, and training activities for growers.

Alternative strategy for multi-pathway synergistic nitrogen and phosphorus removal

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Low-carbon and highly efficient nitrogen and phosphorus removal of wastewater plant remains challenges for conventional activated sludge processes, which are often limited by low biomass concentration, poor settleability, and insufficient metabolic synergy among functional microorganisms. Here, we developed a composite biological system (CBS) using a novel powdered carrier to restructure the sludge micro-environment and enhance nutrient transformation. Pilot-scale validation showed that the CBS system stabilized granular micro-structures and selectively enriched phosphate-accumulating organisms (PAOs) and denitrifiers, such as Alcaligenes, and anammox bacteria (Candidatus Brocadia). These shifts enabled efficient coupling of simultaneous nitrification-denitrification (SND), direct ammonium oxidation (Dirammox), and anaerobic ammonium oxidation (Anammox). Mass balance analysis revealed that the N removal was achieved with multi-pathway synergistic pathways, including the conventional nitrification/denitrification, Anammox and Dirammox, which contributed to the N removal ratio with 92.5%, 6.3% and 1.2% respectively, and the efficiency of biological phosphorous removal has been increased by 51%. This study demonstrated how engineered carriers can reprogram sludge micro-environments to achieve cost-effective, carbon-neutral wastewater treatment, providing a scalable strategy for sustainable urban water management.

The Current Situation and Challenges of Waste Incineration Fly Ash Treatment and Utilization in China

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With the rapid growth of waste incineration capacity, the annual production of solid waste incineration fly ash in China has exceeded 10 million tons. Its safe disposal has become a critical bottleneck constraining the sustainable industry development. Approximately 90% of fly ash is disposed of by solidification/stabilization pre-treatment coupled with landfill disposal in China. While this approach ensures short-term safety, in the long term it not only occupies substantial land resources but also faces risks of pollutant leaching caused by the natural environment. Consequently, the disposal methods for fly ash are actively shifting toward resource utilization in construction materials, including technologies such as washing combined with co-processing in cement kilns to produce cement, high-temperature melting/sintering to produce lightweight aggregates, and low-temperature pyrolysis combined with washing to produce construction products raw materials. However, challenges such as high pretreatment costs and energy consumption, variable composition of fly ash, the lack of a long-term safety evaluation system, and incomplete market access standards for products have hindered the widespread adoption of resource utilization technologies. Currently, while steadily advancing the upgrade of resource utilization, efforts should continue to optimize and strictly regulate the existing landfill disposal. For the use of fly ash in construction materials, it is essential to balance both the processing durability and the long-term environmental safety of the construction products. The key lies in achieving efficient, synergistic removal of "chlorides-heavy metals-dioxins" from fly ash while preserving beneficial components such as calcium-based constituents as much as possible. Only in this way can the sustainable and healthy development of pretreated fly ash in the field of construction material utilization be ensured.

Carbon Emission Reduction Performance Evaluation Under the Construction of "Zero-Waste City" in China: A Case Study

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The construction of "Zero-Waste City" represents a crucial strategy for China to advance reforms in its solid waste management system and progress toward achieving "carbon peak" and "carbon neutrality." During the development of "Zero-Waste City" construction, evaluating the carbon reduction potential across the entire life cycle of various urban solid wastes and identifying effective pathways for pollution and carbon emission reductions can support the formulation and enhancement of solid waste management policies. Taking Weifang City as a case study, this research employed an improved WARM model combined with the emission factor method to calculate the life cycle carbon emissions associated with the generation, utilization, and disposal of various solid wastes in the city. The carbon reduction benefits before and after the implementation of the "Zero-Waste City" initiative were assessed, and future life cycle carbon emissions were projected for the years 2025 (short-term), 2030 (medium-term), and 2035 (long-term). The results indicate that, despite the implementation of the "Zero-Waste City" program, the upward trend in carbon emissions from solid waste sector has not been effectively curbed. Total carbon emissions increased from 186.64 million tons in 2020 to 201.37 million tons CO_2-eq in 2023. The estimated carbon emissions from the waste sector for the short-term, medium-term, and long-term target are 203.27 million tons, 215.81 million tons, and 206.43 million tons, respectively. The municipal solid waste sector contributes the most to carbon emission reductions, with a total reduction of 3.56 million tons. To achieve further reductions in pollution and carbon emissions, key measures include promoting source reduction of municipal solid waste, increasing the recycling rate of renewable resources, optimizing the resource utilization systems for agricultural byproducts such as manure and straw, reducing industrial waste generation intensity, advancing clean production practices, and facilitating the high-value utilization of industrial solid wastes such as fly ash and smelting slag.

Energy Utilization of Biowaste – Production of Biomethane

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The European Union's transition to a circular economy is essential to achieving the energy and climate goals established through the Paris Agreement and the European Green Deal. In 2022, 1.05 billion tons of food waste (including inedible parts) was generated globally, amounting to 132 kg per capita. Food waste, due to its high content of organic matter, contributes to increasing the carbon footprint by polluting the environment. However, food waste can be used as an alternative source of energy, which with its utilization can contribute to the reduction of greenhouse gas emissions and the production of added value products. The main method of achieving the goal of energy production from food waste is anaerobic digestion, as through the appropriate optimization of various stages we can lead to the production of biogas with satisfactory rates of methane content.

In this experiment, a substrate rich in carbohydrates was studied, which was initially subjected to a chemical or biochemical hydrolysis process with the main free variable being the ratio and type of microorganisms and enzymes that participated in the phases of the hydrolysis of the food residues. The parameters monitored for process control and optimization were mainly dry solids, pH, temperature, conductivity, dissolved oxygen, sugars and proteins. The overall degree of organic load degradation and biomethane production was high, while benefits were demonstrated from co-treatment of food waste with sludge from municipal sewage treatment plants. Experimental results indicated that through the optimization of the anaerobic digestion process, a high-quality biogas was produced with a methane content reaching up to 70%.

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Sustainable Management of Endocrine Disrupting Compounds in Potable Water: Integrating Constructed Wetlands towards Water Safety

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The presence of Endocrine Disrupting Compounds (EDCs) in surface waters constitutes a growing threat to public health and aquatic ecosystems, challenging the resilience of conventional drinking water treatment plants. Substances such as bisphenol-A, nonylphenols, and pharmaceutical residues are frequently detected in water bodies, often bypassing traditional treatment stages like chlorination and filtration. In light of the new EU Directive 2020/2184, which introduces stricter monitoring for emerging contaminants, this study reviews sustainable technologies for EDC removal and proposes an integrated management framework.

Specifically, in the present study we evaluated the efficiency of Nature-based Solutions (NbS) and Advanced Oxidation Processes (AOPs) for the degradation of recalcitrant micro-pollutants.

As a case study, we analyze the Aliakmonas River basin in Northern Greece, a critical water source for the city of Thessaloniki. We propose a hybrid model combining the implementation of constructed wetlands at key pollution discharge points to reduce the incoming organic load, followed by solar-driven AOPs at the entrance of the water treatment facility. This synergistic approach aims to minimize the presence of EDCs in the final potable water, ensuring water safety while optimizing energy consumption and promoting circularity in water management.

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SLUDGE MANAGEMENT

Enhancing Digestate Dewaterability from Anaerobic Co-Digestion of Food, Livestock, and Agricultural Wastes

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Anaerobic digestion (AD) is widely applied for sewage sludge stabilization and renewable energy recovery; however, the anaerobic digestion of primary sewage sludge as a standalone substrate is not common practice, primarily due to concerns related to biodegradability, process stability, and energy efficiency. This contribution proposes and evaluates primary sludge AD as a viable treatment option through a series of targeted enhancement strategies, supported by laboratory-scale case studies and a critical synthesis of recent literature. Experimental investigations demonstrated that optimized mesophilic digestion of primary sludge can increase methane yields by approximately 15–25% compared to conventional, non-optimized operation, while maintaining stable process performance. The application of mineral additives, with attapulgite as a representative case, further enhanced methane production by up to 30% and improved solids stabilization, enabling improved downstream valorization of the produced biosolids. Complementary evidence from anaerobic co-digestion and additive-based studies indicates that functional materials such as minerals, biochar, and trace elements can achieve methane yield improvements ranging from 10% to over 35%, depending on substrate characteristics and dosing strategy. By framing primary sludge anaerobic digestion as a technically feasible and energy-efficient alternative, this study provides a practical, case study–driven framework for its implementation in wastewater treatment plants. The results support the integration of targeted, low-cost enhancement strategies to unlock the energy potential of primary sludge and advance circular economy objectives in sludge management.

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Enhancing Digestate Dewaterability from Anaerobic Co-Digestion of Food, Livestock, and Agricultural Wastes

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Anaerobic digestion of food, livestock, and agricultural waste is widely applied for renewable energy recovery and organic waste stabilization; however, the poor dewaterability of the resulting digestate remains a major challenge for downstream handling and membrane-based treatment. This study investigates targeted physical and chemical conditioning strategies to enhance digestate dewaterability, with a focus on improving compatibility with advanced separation processes. Digestate samples were collected from the liquid stream of screw separators at a full-scale anaerobic co-digestion facility. The untreated digestate exhibited extremely low dewaterability, with Capillary Suction Time (CST) values exceeding 2000 s. Among the evaluated treatments, hydrothermal conditioning was the most effective, reducing CST to 582 s through structural disruption and bound water release. Coagulation provided moderate improvement, while combined ultrasonic–thermal treatment demonstrated strong pH dependence, achieving CST values as low as 900 s under optimized alkaline conditions. The results demonstrate that early-stage, process-oriented conditioning—particularly thermal treatment—can substantially improve digestate dewaterability and enable more efficient downstream membrane treatment. This approach offers a practical pathway for integrating digestate conditioning into anaerobic digestion systems to reduce operational constraints and enhance overall process performance.

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Assessment of the instrument-related sensitivity and non-spectral matrix effects in the combination of cloud point extraction with GC-MS/MS: perspectives for analysis of Benzo(a)pyrene and Indeno(1,2,3-cd)pyrene in sewage sludge

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Polycyclic aromatic hydrocarbons (PAHs) are persistent organic pollutants with hazardous effects on human beings and nature. The present study is a part of the development of a green analytical methodology based on the triple combination of microwave micelle-mediated extraction (MW-MME), cloud point extraction followed by re-extraction in hexane (CPE-hexane), and GC-MS/MS, aiming at the group analysis of 16 priority PAHs, including benzo(a)pyrene and Indeno(1,2,3-cd)pyrene, in sewage sludge. It was found that under these conditions, some amount of surfactant (Triton X-100) was co-extracted into the hexane phase during the re-extraction step, which led to the need for a detailed study and evaluation of non-spectral matrix effects in the gas-chromatographic analysis. A noticeable increase in the instrumental sensitivity (positive non-spectral matrix effect), most likely due to the inactivation of the active sites on the GC liner surface by the surfactant, was observed for all studied analytes. To minimize matrix effects without compromising instrumental sensitivity, the injection process optimization was performed, utilizing a central composite design (CCD). The CCD optimization of the PTV injector efficiency included four factors (initial injection temperature, heating rate, maximum injection temperature, and injection time) at 5 levels. The results from the Pareto charts showed that the initial PTV temperature is the most critical factor influencing signals of all target PAHs. Applying response surface methodology (RSM), it was established that an increase in the initial PTV temperature significantly improves sensitivity while reducing the magnitude of the matrix effect except for benzo(a)pyrene and Indeno(1,2,3-cd)pyrene. Considering the analysis of 16 PAHs, the optimal initial injection temperature was identified using two desirability functions (one for the absolute signals and one for matrix effect) at 120 °C. The RSM was applied to establish the optimum values of the other three factors: heating rate 14 °C s-1, maximum temperature 250 °C, and injection time 1 minute (60 s). The developed method provides a reliable, sensitive, and robust approach for the analysis of trace amounts of polycyclic aromatic hydrocarbons (PAHs) with repeatability (RSD $< 11\%$, $n = 10$) for all 16 PAHs, reduced non-spectral matrix effects even for the most problematic (high molecular weight) analytes, especially in complex matrices such as sewage sludge.

Acknowledgements:

This study is financed by the European Union-NextGenerationEU, through the National Recovery and Resilience Plan of the Republic of Bulgaria, project № BG-RRP-2.004-0001-C01

Valorization of Sewage Sludge Biochar as UV Stabilizer in Recycled PET Composites

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The growing demand for high-value applications of recycled polymers and wastewater-derived residues highlights the need for integrated approaches to circular resource management [1]. In this work, composites based on recycled poly(ethylene terephthalate) (rPET) containing four different loadings of biochar (0.5, 1, 2.5, 5 % wt.) produced from sewage sludge were prepared and systematically characterized. The structure and thermal behavior of the materials were investigated by attenuated total reflection Fourier transform infrared spectroscopy (ATR-FTIR), differential scanning calorimetry (DSC), thermogravimetric analysis (TGA) and intrinsic viscosity measurements, in order to correlate molecular structure, crystallinity, and thermal stability with biochar content. Subsequently, the composites were subjected to controlled UV irradiation to assess the potential of sewage-sludge-derived biochar as a UV stabilizer for rPET [2],[3]. Changes in surface chemistry were quantified before and after exposure, enabling direct comparison of the UV resistance among the different formulations [4]. The results demonstrate that the incorporation of sewage sludge biochar can enhance the photostability of recycled PET while simultaneously valorizing a problematic wastewater by-product, supporting a more sustainable and synergistic use of waste streams in polymer engineering.

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Nutrient Recovery from Anaerobic Digestate via Chlorella sorokiniana: Towards Sustainable Biostimulant Products

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Anaerobic digestate is a nutrient-rich by-product of biogas production that can pose environmental risks if not properly managed, while also representing a valuable secondary resource for circular economy strategies. This study investigates the cultivation of Chlorella sorokiniana in digestate-derived media, emphasizing photobioreactor operation, nutrient recovery (N/P), and the production of protein-rich biomass relevant to biostimulant-oriented products.

Cultivation is performed in a closed, pilot-scale photobioreactor equipped with LED illumination, controlled aeration, and continuous monitoring of pH, temperature, and dissolved oxygen. Prior to pilot operation, laboratory-scale trials support strain acclimation and screen digestate dilution levels and nutrient loads to identify operating ranges enabling stable growth while limiting inhibitory effects linked to elevated ammonium and pH shifts.

Microalgal growth performance and biomass productivity are monitored to evaluate culture stability. In parallel, nitrogen and phosphorus concentrations in the liquid phase are measured to quantify nutrient recovery and describe nutrient dynamics under digestate-based conditions. Particular attention is given to the interplay between nutrient availability, pH variation, and microalgal activity, as these factors are critical for reliable operation and for coupling microalgal cultivation with digestate management.

The study evaluates the feasibility of cultivating *C. sorokiniana* in digestate-derived media and highlights the potential for partial nutrient recovery from the liquid phase. Post-cultivation processing is considered to obtain protein hydrolysates (amino acid- and peptide-rich fractions produced via controlled hydrolysis) with potential plant biostimulant activity. Pot experiments are included to examine their effects on plant growth under controlled conditions.

Overall, this work supports integrated strategies combining digestate treatment, nutrient recycling, and biomass valorization, enabling more sustainable and circular approaches in environmental management and agriculture.

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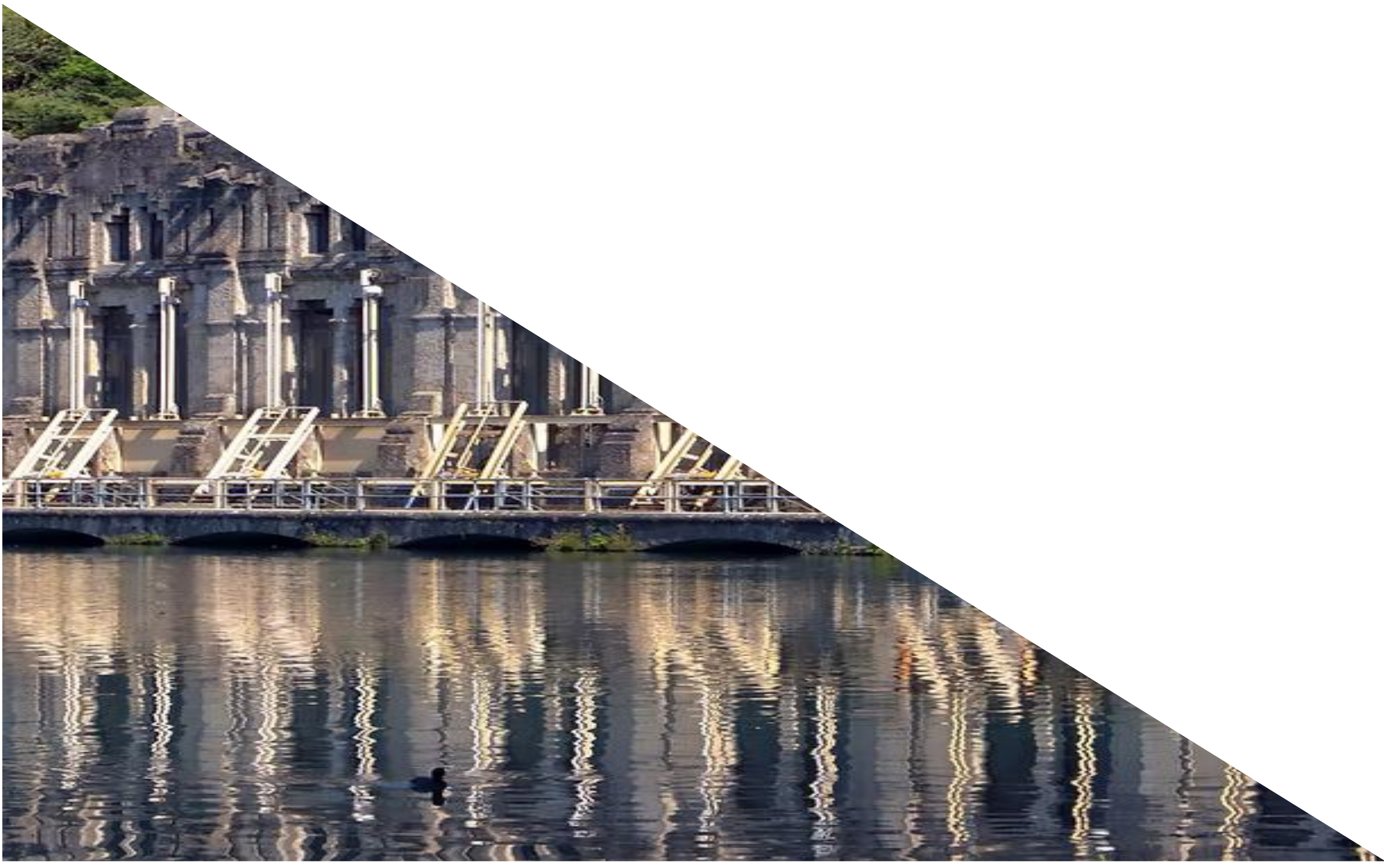
MANAGEMENT OF WATER AND ENERGY PLANTS



Towards Zero Pollution Across the Urban Water Cycle

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Rapid urbanisation, industrial activity, and climate change contribute to urban water pollution, which poses a serious risk to public health and the environment by degrading water quality across urban water systems. This deterioration is largely associated with diffuse pollution affecting surface and groundwater bodies, leading to biodiversity loss, degradation of aquatic ecosystems, and further pressure on the global water crisis. Existing urban water management plans lack a comprehensive and integrated approach to water quality monitoring, leading to insufficient coverage of critical pollution sources and pathways. Timely detection, prevention, and response to these pressures are essential to ensure clean and safe water resources and to support a resilient and sustainable water future across Europe that protects both environmental quality and public health. AQUAMON introduces a new generation of intelligent water monitoring technologies designed to protect urban environments and public health. The system combines real-time sensors, autonomous robots and advanced data analytics to deliver continuous insight into water quality across the entire urban water cycle. By deploying advanced sensors directly in the field, AQUAMON enables fast, reliable and high-resolution monitoring of chemical, biological, physical and microplastic pollutants. AQUAMON also expands monitoring capabilities through the use of aerial, surface and underwater robots that can access areas that are difficult or unsafe for human operators, enabling precise sampling, mapping and infrastructure inspection. All environmental data are integrated within a single analytics platform that unites sensors and robotics, supporting consistent analysis, transparent reporting and trustworthy environmental assessments supported by explainable AI models. AQUAMON will contribute to i) securing high-quality drinking water, ii) improving the biological capacity of wastewater treatment plants, iii) reducing flood risks through integrated sewer and treatment plant control, iv) supporting safe bathing opportunities in urban waters, restoring rivers and coastal waters, and v) enhancing wastewater quality towards reuse standards. By enabling data interoperability and cybersafe data sharing, AQUAMON makes advanced water intelligence accessible to operators, decision-makers and citizens, supporting European climate resilience and zero-pollution goals and promoting sustainable urban water management.