NATURAL DEEP EUTECTIC SOLVENTS FOR MITIGATING PER AND POLYFLUOROALKYL SUBSTANCES, TIRE WEAR, AND OTHER PERSISTENT ORGANIC POLLUTANTS IN AQUATIC ENVIRONMENTS

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Abstract. The pervasive contamination of aquatic ecosystems by per- and polyfluoroalkyl substances (PFAS), micro- and nanoplastics (MNPs), tire wear organic particles (TWOP), and other persistent organic pollutants (POPs) constitutes one of the major environmental challenges of the 21st century. These synthetic compounds, characterized by exceptional chemical stability and resistance to degradation, are now distributed worldwide and present significant risks to the integrity of our ecosystem and human and animal health. Conventional remediation technologies, including activated carbon adsorption and membrane filtration, are limited in terms of efficiency, cost, energy consumption, and hazardous waste generation. This comprehensive review examines the evolving use of Natural Deep Eutectic Solvents (NADES), a novel class of green solvents derived from naturally occurring, biodegradable compounds, as a sustainable, highly effective alternative for removing these persistent pollutants from water. NADES operate through powerful mechanisms of liquid-liquid extraction and adsorption, leveraging extensive hydrogen bonding networks to achieve remarkable removal efficiencies exceeding 99% for target contaminants. We analyze current knowledge on NADES fundamentals, contaminant characteristics, extraction mechanisms, comparative advantages over conventional methods, and technical challenges related to their viscosity, scalability, and economic viability. As part of our ongoing DEEP-CLEAN project, we critically analyze experimental evidence, discuss regeneration strategies essential to implementing the circular economy, and evaluate the regulatory landscape driving innovation in this field. NADES represents a paradigm shift toward sustainable water treatment, which offers a technically viable, economically competitive, and environmentally friendly solution to address the global crisis of persistent contamination in aquatic environments. We propose future research directions that integrate computational design, artificial intelligence (AI), and process optimization to facilitate its transition from laboratory experiments to industrial-scale deployment.

Keywords: NADES; PFAS: TWOS: persistent organic pollutants; microplastics; nanoplastics; green chemistry; liquid-liquid extraction.