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Tyre Wear Particles as Reactive Polymer–Metal Pollutants: Dual-Tracer Insights into Aggregation, Transformation, and Mobilisation in Urban Drainage Systems

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Tyre wear particles (TWPs) are increasingly recognised as a major and persistent polymer-based pollutant, contributing substantially to the burden of micro- and mesoplastics in urban environments. Their complex composition—an elastomer matrix enriched with additives, fillers, and associated metals—positions them as a chemically reactive component of the broader pollutant cocktail now shaping Earth's surface geochemical processes. Despite their ubiquity, the environmental behaviour of TWPs remains poorly constrained, particularly their interactions with mineral substrates, co-mobilised metals, and variable redox and hydrological conditions. To address these gaps, we present the first integrated application of elastomer-specific polymer markers (PyroTGA-GC-MS) and elemental signatures (ICP-MS) measured on identical environmental samples to assess the accumulation, transformation, and mobility of TWPs within a roadside drainage system constructed to UK National Highways specification (CG501).

Samples collected along the pathway from the road surface to the Lambourn River under contrasting dry-weather and stormflow conditions reveal that TWPs occur not only in microplastic-sized fractions but also as larger aggregated material, demonstrating their propensity to form multi-pollutant complexes with coarser particles. This challenges current assumptions regarding the size distributions relevant for monitoring and environmental risk assessment. During storm events, sequestration efficiency decreases sharply, leading to enhanced export of TWP-rich material and illustrating the vulnerability of existing infrastructural systems to episodic hydrological forcing. Moreover, divergence between Zn-based and polymer-based markers under high-flow conditions indicates Zn leaching and highlights the chemically dynamic nature of TWP degradation, with direct implications for tracing pollutant interactions, transformation processes, and biogeochemical fluxes.

By contextualising TWPs within the broader framework of persistent organic pollutants and multi-pollutant systems, this study offers new mechanistic insight into their accumulation pathways, environmental reactivity, and mobility across interconnected compartments. These findings underscore the need to integrate polymer chemistry, metal geochemistry, and environmental materials science to better predict pollutant behaviour and exposure pathways, ultimately informing mitigation strategies and policy responses in increasingly urbanised and contaminated landscapes.