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Monitoring Mobile Metals: A Pb-Zn Isotopic Approach to Trace Metal Pollutant Sources in Rivers

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Dissolved metal concentrations in rivers are influenced by a combination of natural processes and anthropogenic activities, with inputs that vary in time and space. Previous studies have shown that dissolved heavy metal concentrations respond strongly to changes in discharge, both in contaminated and pristine catchments.

Environmental regulations (such as the Water Framework Directive) establish recommended limits on heavy metals in freshwater systems, yet these limits are frequently exceeded. Effective remediation requires accurate identification and quantification of the relative contributions from different pollutant sources. Concentration measurements alone are insufficient to resolve sources when hydrological variability and within-catchment processes are considered. To address this limitation, we integrate concentration data with metal isotope analyses, which provide tools to trace source inputs across a range of flow conditions.

We apply a novel multi-tracer framework that combines trace element and dissolved organic carbon (DOC) concentrations, together with stable zinc (Zn) and radiogenic lead (Pb) isotope ratios, to identify and distinguish sources of dissolved heavy metal contamination. This approach is tested in the River Wear catchment, a historic Pb–Zn mining region in northeast England, UK. In this catchment, dissolved metal loads in the headwaters are dominated by legacy mine wastes, while downstream sections increasingly reflect inputs from agriculture and urban activities, including wastewater discharges and road runoff.

Catchment-wide transect sampling was conducted under low, medium, and high flow conditions. We show clear and significant shifts in Zn isotope composition associated with changing river discharge. The combined use of Zn and Pb isotopes alongside complementary chemical tracers improves the resolution of source discrimination between historical mining and contemporary anthropogenic sources and also provides insight into key catchment processes such as mixing, dilution, and hydrologically-mediated mobilisation. Overall, this integrated approach offers a robust tool for source apportionment and supports the design of targeted remediation strategies in rivers affected by legacy contamination.