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Quantitative analysis of nitrate source attribution in the Weihe River Basin using dual nitrate isotopes

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Nitrate is one of the primary forms of nitrogen in surface water, and its elevated concentrations can lead to significant ecological problems, such as water eutrophication, and also posing a potential risk to human health. Accurate identification and quantification of nitrate sources are essential for addressing nitrate pollution in riverine systems. The Weihe River, a resource-dependent region, has experienced a persistent increase in nitrate levels in recent years, which is largely attributable to the intensification of anthropogenic activities, leading to a cascade of ecological challenges. This study investigates the spatial variability of nitrate concentrations and isotopic compositions ($\delta^{15}N\text{-}NO_3^-$ and $\delta^{18}O\text{-}NO_3^-$) in surface water across different land-use types (construction land, cultivated land, and forest land), and employs a Bayesian isotope mixing model to quantitatively apportion nitrate sources. The findings reveal marked disparities in nitrate concentrations and isotopic signatures among the land-use types ($P < 0.01$). Specifically, nitrate concentrations in construction land (130.2 ± 38.3 mg L^{-1}) and cultivated land (95.4 ± 12.9 mg L^{-1}) were significantly higher than those in forest land (16.0 ± 1.9 mg L^{-1}) ($P < 0.01$). Isotopic values for $\delta^{15}N\text{-}NO_3^-$ and $\delta^{18}O\text{-}NO_3^-$ in forest land (4.52 ± 0.56‰ and 5.55 ± 0.71‰, respectively) were significantly lower compared to those in construction land (18.26 ± 1.31‰ and 8.79 ± 1.14‰) and cultivated land (18.35 ± 1.64‰ and 7.70 ± 1.01‰) ($P < 0.01$). Source apportionment analysis identified manure and sewage as the predominant nitrate sources in construction land (58.1 ± 8.5%) and cultivated land (53.3 ± 19.0%), whereas soil nitrogen (26.2 ± 2.8%) and NH_4^+ fertilizer (24.6 ± 4.4%) were the primary contributors in forest land. These results underscore the profound impact of human activities, particularly sewage discharge and improper livestock manure management, on nitrate enrichment in surface waters. The study provides critical insights for formulating targeted strategies for water quality management and sustainable development in the Weihe River basin.