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Assessing the spatio-temporal dynamics of nitrate in an alluvial aquifer: Varaždin aquifer case study

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Nitrate contamination poses a significant threat to drinking water quality. This is especially pronounced in agricultural watersheds, where the intensive application of fertilizers and manure, combined with well-drained soils, makes shallow alluvial aquifers highly vulnerable to contamination from surface sources. To better understand and manage this issue, a detailed investigation into the spatio-temporal dynamics of nitrate was conducted in the Vinokovščak wellfield of the Varaždin alluvial aquifer using a transient groundwater flow and nitrate transport model. A water balance analysis revealed that groundwater recharge is mainly driven by infiltration from precipitation and river inflow. Precipitation mobilizes nitrate and elevates its concentrations in groundwater, whereas river inflow contributes to dilution. Nitrate transport simulations corroborated the hypothesis of a consistent nitrate input from agricultural activities and showed that nitrate accumulates in the unsaturated zone before gradually migrating downward to the water table. Isotopic signatures ($\delta^{15}N$ and $\delta^{18}O$ of nitrate) indicated soil organic nitrogen, manure, and sewage as the primary nitrate sources. Evidence also suggests that localized and short-term denitrification may occur, though this offers only a partial and unreliable remedy for the nitrate issue. Particle tracking helped delineate zones with varying travel times within the wellfield catchment, identifying areas with short travel times as particularly susceptible to nitrate leaching and to increased nitrate levels in pumping wells. Overall, the modeling framework provides a practical tool for quantifying nitrate contributions from surface sources and understanding the key controlling factors, offering valuable insights for managing groundwater quality in similar hydrogeological settings.

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