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Quantification of groundwater inflow into a river using environmental tracers and substances of anthropogenic origin (Ammer, Tuebingen, SW Germany)

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Characterization of groundwater-surface water interactions remains challenging, especially in anthropogenically affected and geologically complex river systems. In this study, groundwater inflow into the Ammer River was quantified by optimizing exfiltration rates in an implicit numerical model (FINIFLUX) to measured data of several environmental tracers (e.g., sulfate (SO_4^{2-}), radon (^{222}Rn)) and organic conservative pollutants like carbamazepine and sulfamethoxazole emitted via a wastewater treatment plant (WWTP). Modelling results of the selected tracers were compared.

The investigated Ammer River is strongly karstified and anthropogenically modified (mill canals, weirs, numerous artificial inputs) but representative for many small river systems in Europe. ^{222}Rn activities in the river ranged from 500 to 3300 Bq m^{-3} and SO_4^{2-} concentrations from 224 to 291 mg L^{-1}. Concentrations of carbamazepine (90-130 ng L^{-1}) and sulfamethoxazole (55-100 ng L^{-1}) in the river water result from effluents of a WWTP. All tracers indicate major local groundwater inflows over the 6 km river reach. Additional high peaks mainly observed in ^{222}Rn activities indicate inputs along geological fault lines, whereby increasing concentrations of carbamazepine and sulfamethoxazole may be attributed to inputs of groundwater contaminated by infiltration of wastewater from a nearby WWTP. ^{222}Rn-based calculations showed the best optimization performance (R^2=0.90) and result in a reasonable cumulative groundwater inflow of 0.274 m^3 s^{-1} (28.5% of total discharge) for the investigated reach. Poor optimizations for the other tracers may be due to the diurnal pattern of ion concentrations induced by the WWTP and measurement uncertainties and the small concentration differences between river water and groundwater for carbamazepine and sulfamethoxazole.

In our case study, ^{222}Rn seems to be the most suitable environmental tracer despite uncertainties in degassing and determination of the groundwater endmember concentration. However, only a multi tracer approach can account for the complexity of the investigated river system and may thus be indispensable for future investigations aiming to understand groundwater-surface water interactions.