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# Integration of major ion chemistry and stable isotope data with hydrogeological modelling to infer groundwater pathways

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Determination of groundwater pathways and groundwater residence time is important in groundwater resources management. A variety of methods exist to differentiatie infiltration zones from seepage zones and to quantify their relationship. For this purpose we combined data on major ion chemistry and stable isotopes with calculations from a hydrogeological model whose detailed hydrostratigraphic units were derived from a dense network of cone penetration tests.

The analysis was done to quantify the connectivity between two aquifers separated by a distinct clay layer several meters thick. The clay layer plays an important role in the relationship between infiltration and seepage zones The upper aquifer has developed in a sequence comprising the sandy Formations of Mol and Kasterlee, while the lower aquifer mainly consisted of the sandy glauconite-rich Diest Formation.

The detection of isotopes as they occur in nature is an invaluable tool in studying the behaviour of water in the hydrological cycle. Owing to the difference in mass, stable isotopes behave slightly different in physical, chemical, and biological processes. For instance, due to evaporation and exchange processes in the atmosphere, the stable isotopes $^2$H/$^1$H and $^{18}$O/$^{16}$O become fractionated. The resulting small changes in isotopic concentrations may yield information on the circulation of water, e.g. from the transition of precipitation to soil infiltration and recharge to groundwater, with further variations in young shallow groundwater in infiltration zones and older groundwater from deeper aquifers that drain into the seepage zones.

In the present study, $^{18}$O and $^2$H were measured in rainwater, surface water, and groundwaters to reveal interactions among them. Rainwater was included in the analysis for tracing groundwater recharge, while the analysis of surface water in terms of stable isotopes was necessary to determine the contribution of deep groundwater to river base flow.

The hydrochemical analyses showed existence of different groundwater compositions for the upper and lower aquifers. All groundwaters seem to be meteoric in origin, whereby the alkalinity increases with depth while the cations shift from divalent Ca to monovalent Na. A distinct cluster of data points for the upper aquifer was evident, characterised by a strong sulphate component (between 60-80%). Based on the cation analysis, most samples are of the sodium or potassium type, where in general K and Na are dominant, while fewer are from the calcium type. The water composition in the lower aquifer (Diest Formation) is quite different compared to the upper aquifer. The anions are dominated by bicarbonate (bicarbonate type groundwater), while Ca becomes the most important cation (calcium type groundwater). This could be related to the higher Ca-concentrations observed in the Diest mineral (i.e. carbonate) phase. The river water has a composition inbetween that of both aquifers, suggesting mixing of both waters in the seepage zone.

Analysis of stable isotope data reveals the existence of two clusters for the hydrostratigraphic units that define the upper and lower aquifer: one for the units above the Kasterlee clay (i.e., Mol and Kasterlee Sands), and one for the Diest Sands. It appears that the shallower and younger water from the Mol Sands is slightly less depleted in $^2$H and $^{18}$O in comparison with water from the deeper Diest Sands (for the latter aquifer deviations from the meteoric lines are larger both for $^{18}\delta$ and$^2\delta$). These two clusters thus confirm the geochemical analysis.

The groundwater geochemistry and stable isotope data confirmed the general flow paths obtained from running the groundwater flow model: infiltration zones that are mainly connected with the seepage zones along the Kleine Nete river via shallow groundwater pathways. There is also confirmation from the groundwater geochemistry that the upper and lower aquifers are well separated by the clay aquitard, although in the seepage zone strong upward gradients across the clay exist.