Understanding mechanisms of quality degradation as an essential tool for remediation and management in Northwestern India

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India extracts more groundwater than any other country. On its own, it accounts for nearly a third of all groundwater use worldwide. While most of this water is used for irrigation, the World Bank estimates that nearly 85% of drinking water supplies in India rely on groundwater. For Northwestern India, with its drought-prone arid climate and uneven access to surface water, this reliance on groundwater is particularly precarious. From a quantity perspective, unrestricted withdrawals and uncertainties in the face of climate change threaten both current and future water accessibility. At the same time, rampant quality issues have important implications for the usability of available groundwater.

We use data from 385 groundwater wells in the Indian States of Punjab, Rajasthan, and Gujarat to investigate the mechanisms of quality degradation in the region. Using multiple isotopic and geochemical tracers, we show that both geogenic and anthropogenic sources sources affect the water quality, combined with geochemical processes (e.g., reverse base-exchange reactions) that further exacerbate the mobilization of contaminants from the aquifer rocks. We use Sr isotope ratios in groundwater to delineate the source lithology and water-rock interactions across the study area. We measured high concentrations of nitrate and dissolved organic carbon, which clearly indicate anthropogenic inputs. These human derived compounds can in turn interact with naturally high concentrations of halides to form toxic disinfection by-products when disinfectants like chlorine are added during routine drinking-water treatment. Additionally, $\delta^{18}O$ and $\delta^{2}H$ indicate how aquifer permeability and multiple water sources, including imported water, can have large impacts on local groundwater balance and quality. Overall, these analyses provide vital information for water managers to make decisions regarding treatment, remediation, and source management, which will help authorities in India to address critical challenges regarding water availability and quality in India.