Hydroclimatic controls on groundwater quality evolution in basaltic aquifers: process-based insights from a state-scale dataset in India

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Hydroclimatic variability influences groundwater quality evolution in semi-arid hard-rock aquifers. Using a multi-year (2016–2018) WRIS dataset from basaltic aquifers in India, the present study evaluates spatiotemporal groundwater chemistry through D-Piper diagrams, Gibbs plots and the Oregon water quality index. Groundwater quality deteriorated during the 2017 drought, when reduced recharge coincided with a sharp rise in NO_3^- exceedances (~40% of samples) alongside elevated total dissolved solids and total hardness, whereas late-season rainfall in 2018 promoted dilution and recovery. Results indicate a dilution–mobilisation mechanism linking hydroclimatic variability with rock-water interactions and anthropogenic inputs, emphasising adaptive groundwater management across basaltic aquifer systems globally.

Keywords: Basaltic aquifers, groundwater quality, hydroclimatic variability, nitrate contamination, Oregon water quality index

Maharashtra, one of India's most populous states, relies heavily on groundwater resources. Groundwater quality in Maharashtra is monitored by the Groundwater Survey and Development Agency (GSDA)[10], Central Groundwater Board (CGWB)[11], and Maharashtra Pollution Control Board (MPCB)[12]. Collectively, these agencies monitor 1407 locations across multiple districts and hydrogeological settings. While geology plays a significant role in shaping groundwater chemistry, contamination is largely driven by anthropogenic factors, including agricultural runoff, industrial discharge, and urbanization[13,14]. Studies have reported elevated levels of contaminants such as NO_3^-, F^-, total dissolved solids (TDS), Cl^-, SO_4^{2-} and HCO_3^-, often exceeding Bureau of Indian Standards (BIS) limits,[15,16] posing risks to human health[17–20].

Despite extensive monitoring, many groundwater assessments remain primarily descriptive, emphasising spatial characterisation[2] rather than examining how hydroclimatic variability influences groundwater quality evolution across time. We investigate climate-driven controls on groundwater quality evolution using a state-scale Water Resource Information System (WRIS; India-WRIS)[21]