Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.33771

Changing Rates of Groundwater Recharge: Impacts of Climate Change and Agriculture

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Groundwater, the world's largest freshwater reservoir, acts as a critical buffer against climate change and is primarily replenished by monsoonal recharge in India. We conduct a case study in the agriculturally intensive Nanoor region of Birbhum district, India, within the lower Ajay River basin to determine the impact of climate change and increasing irrigation on groundwater recharge. Although lithology and aquifer characteristics indicate high recharge potential of the study area, the diminishing difference between pre- and post-monsoon groundwater levels over recent decades suggests a progressive decline in net recharge.

We analyse stable isotopes ($\delta^{18}O$, $\delta^{2}H$) of groundwater (GW), surface water (SW), and rainwater (RW), together with land-use/land-cover (LULC) change and hydroclimatic analyses to determine potential causes of the changing recharge rates.

Stable isotopic analysis of monthly water samples from five GW and five SW sites alongside RW and monsoonal rainfall data from an automatic rain gauge (collected between October 2023 and September 2024) reveals a strong linkage between SW and RW, with RW closely following the Global Meteoric Water Line (GMWL). In contrast, GW exhibits minimal seasonal isotopic variability and shows little correspondence with either SW or RW. The $\delta^{18}O$ values of GW (~ -5‰ for all sites) show limited variability throughout the year and are markedly offset from the volume-weighted mean $\delta^{18}O$ of monsoon RW (~-9.9‰). Line-conditioned excess (lc-excess) further corroborates these observations by indicating weak modern meteoric influence.

These results point to reduced recharge driven by altered rainfall–infiltration relationships and enhanced surface runoff linked to the rapid expansion of built-up areas. Simultaneously, increasing gross cropped area, dominated by irrigation-intensive rice, has intensified groundwater abstraction. ERA5-Land reanalysis indicates rising runoff in recent years despite no significant long-term trends in annual rainfall or extremes. High rainfall–runoff elasticity further suggests a tendency toward rapid runoff generation. Collectively, the evidence indicates that emerging hydrogeological vulnerability in the Nanoor region is largely anthropogenic, with increased abstraction and reduced effective infiltration diverting monsoonal rainfall away from groundwater recharge. Our results indicate that the impacts of climate change and increasing irrigation pose serious risks to long-term groundwater sustainability in agriculture-dominated regions of India.