Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.33892

Tracing Surface Water–Groundwater Interactions and Solute Mobilization in the Ganges Delta Front Aquifers Using Stable Water Isotopes: Implications for Freshwater Security in the Indian Sundarbans

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The Indian Sundarbans, a UNESCO World Heritage Site and Biosphere Reserve, located in the western, tide-dominated part of the Ganga-Brahmaputra-Meghna (GBM) delta and adjoining to the Bay of Bengal is facing immense freshwater scarcity fueled by climate change and anthropogenic interventions. Therefore, this study has investigated the current scenario of deep groundwater, only available freshwater source in the region, from inland to near- coastline aquifer and the surface water-groundwater interaction-derived solute mobilization by stable water isotopes ($\delta^{18}O$ and $\delta^{2}H$) and salinity concentration. Results revealed that despite an increasing rainfall trend, groundwater levels have dropped significantly over the past decade indicating a limiting the recharge of aquifer plausibly because of delayed response of aquifer matrix to rainfall. Groundwater salinity and δ18O values varied widely in inland aquifer (0.7–9 PSU, $\delta^{18}O$: −2.8 to −0.5‰), while near-coastline aquifer a narrower variation was observed (salinity 0.8–1.2 PSU, $\delta^{18}O$: −2 to −0.6‰). Groundwater in both inland and near-coastline were closely aligned with the GMWL and LMWL, indicating direct meteoric recharge. This was further supported the by average d-excess value of groundwater in inland and near-coastline i.e., -2. ± 1.7‰, -2 ± 1‰, respectively. River water, with high salinity (24 PSU in inland), appears to be a major source of saline intrusion in inland aquifer, in contrary, seawater near-coastline aquifer (salinity: 33 PSU) has elevated the groundwater salinity. Consequently, this interaction is suggesting the potential pathways of SW-GW interaction and solute mobilization contributing to groundwater vulnerability in the study area. Further, the isotopic analysis unveiled that that the inland groundwater was more depleted indicating monsoonal rainfall recharge with very less maritime influence, while the near-coastline groundwater indicates enriched isotopic signature suggesting possible vertical mixing. Eventually, this mixing raises a critical concern for water security. Therefore, these integrated isotopic and geochemical signature-based approach to understand the groundwater vulnerability serve as an effective decision-support tool for sustainable groundwater management in the coastal regions to achieve Sustainable Development Goal-6.