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Hydrochemical attributes and Fluoride release in multi-tier aquifer system of densely populated region in the Central Ganga Plain, India

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Central Ganga Plain (CGP) covers one of the most populous regions of Southeast Asia and is characterized by the abundant availability of shallow groundwater conditions facilitating intensive agriculture practices. Recently, naturally occurring contaminants such as fluoride, arsenic, and uranium have also been reported throughout the CGP, thus limiting the availability of drinking water to some extent. The current scenario of groundwater quality aided with prolonged negligence of excessive groundwater abstraction, increased anthropogenic contaminants, and climatic perturbations will further pressure groundwater sustainability. The present study was carried out in urban and rural parts of CGP to understand hydrochemical evolution and fluoride release mechanism in the groundwater using historical water levels records, subsurface framework, high-resolution hydrochemical data, and stable ($\delta^{18}O$ & $\delta^{2}H$) isotopic composition of groundwater, rainfall, and surface water. The results of chemometric, and Multivariate Statistical Analysis (MSA) showed groundwater chemistry is primarily a function of the minerals present in the soil, and independent of the groundwater flow direction due to local scale heterogeneity imparted by alternate sequences of clay, silt, sand layers of varying thickness. Freshwater types of Ca-HCO_3, Ca-Mg-HCO_3, and Mg-HCO_3 occurrence are linked to the calcite and dolomite nodules present in the older alluvium of the study area. More evolved water types of Ca-Na-HCO_3, Ca-Mg-Cl, and Na-HCO_3 were observed mainly in shallow groundwater levels that cause the formation of sodic saline soils Na_2CO_3, $NaHCO_3$, and Na_2SO_4. Fluoride-enriched groundwater is limited to shallow groundwater (average borewell depth 32m), possesses alkaline condition, Na-HCO_3 water facies, low Ca^{2+}, and an enriched $\delta^{18}O$ signature, which reveals F^- mobilization from minerals such as micas and amphiboles present in the soil. The outcome of this work provides insight into understanding the causes of F^- contamination in groundwater and aims to contribute in developing sustainable management strategies.