# Abstract

The groundwater chemistry and quality of an area is dominated by reaction of the groundwater with the aquifer matrix (rock). The present study delineates the solute sources and water – rock interaction processes taking place in the high-altitude aquifers of the Indus River basin of Ladakh, India. Geochemical mass-balance, stable ($^{18}O$ and $^{2}H$) and radio ($^{87}Sr/^{86}Sr$) isotope systematics and thermodynamic reaction path modelling approaches were applied to elucidate the primary objectives. Groundwater and aquifer matrix were sampled from different tectono –stratigraphic units of the Indus – Tsangpo Suture Zone (33°40'N, 75°29'E – 35°0'N, 78°10'E). Aquifers are composed of fluvial sediments in river valleys and adjoining rocks, ranging in composition from ultrabasic to acidic and from carbonate to siliciclastic. The mildly reducing to oxidizing groundwater are of Ca – $HCO_3$, Ca – Mg – $HCO_3$ type. Solute mass balancing suggests the groundwaters are affected by combined carbonate – silicate weathering pathways. Silicates weather to kaolinite, vermiculite and illite. Thermodynamic calculations suggest groundwater are supersaturated in Fe oxy(hydr)oxides and in equilibrium with kaolinite. Distribution of groundwater contaminants like arsenic (As) and fluoride ($F^-$) show lithological control. High As waters occur in basaltic and high $F^-$ in granitoid aquifers. Groundwater $^{87}Sr/^{86}Sr$ greatly exceed those of typical carbonates, suggesting significant contribution of silicate weathering with multiple silicate sources. The $^{87}Sr/^{86}Sr$ ratios of groundwater in the granitoid, sedimentary, and ophiolitic aquifers matches well with their whole-rock values, establishing them as their solute sources. Strong mismatch between aqueous and solid phase $^{87}Sr/^{86}Sr$ signatures in basaltic aquifers suggests solutes in them is derived from sources outside the suture zone, most likely the Himalayas. Reaction path modelling with different rock – water ratios

predicted precipitation of smectite, kaolinite and amorphous silica when recharge water reacts with basic and granitic matrix and break-down of serpentine to form amorphous silica, hematite, and talc. Analyzed water chemistry is best approximated by rock/water ratios of 1/1000 and 1/100. Concepts discussed so far, when applied to aquifers of the Andean and Himalayan orogenic systems holds true and is able to explain the contrasting hydrochemistry, evolutionary pathways and contaminant mobilization mechanisms in light of regional geologic, climatic and anthropogenic factors.

**Keywords:** Groundwater, Upper Indus River aquifers, Indus – Tsangpo Suture Zone, water – rock interaction, $^{87}Sr/^{86}Sr$, Ladakh