Implications for water cycle dynamics in the Upper Jhelum River Basin of North-Western Himalayas based on hydrogen and oxygen isotope signatures of precipitation, surface water, and groundwater

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We have used stable isotopes of oxygen and hydrogen (δ¹⁸O and δD) which are important tracers for understanding various hydrological processes, to assess the spatial and temporal variability due to dual moisture sources in the Upper Jhelum River Basin (UJRB) of the north-western Himalayan region. The HYSPLIT back trajectory analysis shows large variability in spatial moisture transport pathways over the region during Southwest monsoon (SWM) and is mainly restricted to the Mediterranean Sea during Western disturbances (WDs). The isotopic composition of precipitation is significantly controlled by temperature and Relative Humidity during precipitation events from WDs; however, this control is found to be weak during the SWM.

Stable isotope signatures of precipitation are found to show a well-defined altitudinal effect (δ¹⁸O=0.19‰/100m) and a negative correlation with ambient temperature (R² = 0.65, p<0.01 for WDs & R²=0.48, p>0.1 for SWM). Mixing various tributary waters with different isotopic compositions leads to variability in the Jhelum River’s (JR) isotopic composition along its course. The observed spatial variability of δ¹⁸O and d-excess results from the exchange processes between groundwater and surface water. The higher depletion of precipitation during WDs leads to depletion of surface and groundwater and produces enrichment due to the evaporative loss of heavier isotopes due to drier weather conditions during SWM. Evaporation signals are more prominent in shallow groundwater (SGW) and lake water, indicating SGW being discharged in the proximity of lake water bodies. The isotopic values in the upper reaches are observed to be depleted, potentially due to inputs from melting glaciers and snow. In the middle, it reaches slightly enriched, likely due to shifts in groundwater and rainfall inputs. In the downstream, due to increased residence time and flat topography, the isotopic composition is relatively enriched, potentially related to the evaporative losses of heavier isotopes. The d-excess values in UJRB are found to vary between 11‰ to 20‰ with an average value of ~17‰, which is relatively higher than the long-term average observed for the Indian summer monsoon (~8‰), and Upper Indus in the Ladakh region (11.7‰) but almost similar to observed for Lower Indus (18‰).

The contribution of moisture from each source (WDs and SWM) are estimated using a two-component mixing model. The moisture source contribution over UJRB via WDs is 75%(±20) from the Mediterranean Sea and 20%(±10) from SWM. WDs contribution over UJRB is higher than in the
Trans-Himalayan region in the Ladakh (Indian sector in the east) but smaller in Lower Indus Basin (Pakistan sector in the west). Hence, the influence of moisture of WDs decreases from west to east along the Himalayan region. This work based on stable isotope geochemistry of oxygen and hydrogen highlights the effects of meteorological and physiographic controls on the moisture dynamics and contributes to explain the spatial and temporal variability of hydrologic processes in the region.