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Quantitative modeling of stable isotopes data to delineate aquifer recharge area. Application to the Bromo-Tengger stratovolcano (Indonesia)

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The precise estimation of aquifers' recharge, and location of their recharge area, is mandatory both to preserve (quality) and manage (quantity) groundwater resources. We thus present in this study a methodology aiming at quantitatively assessing and locating aquifer's recharge areas. It combines the use of the stable isotopes local meteoric water line with elevation-dependent groundwater budgets. This methodology is applied to the northern flank of the 2700 m high Bromo-Tengger stratovolcano (East Java, Indonesia). This flank of the volcano recharges a large volcanosedimentary aquifer located at its feets and gives rise to exceptional artesian springs such as "Umbulan", whose discharge is higher than 3500 L.s-1. This spring is used to supply Surabaya city, the second biggest city in Indonesia.

The methodology is 3 steps. (i) The local meteoric δ18O gradient is computed from small local springs regularly located along the northern flank of the volcano; after δ18O stability checking, and hydrogeological assessment of their recharge area, they can be considered as unbiased "local rain gauges". This methodology notably enables to account for artefacts such as preferential "selection" of rainy season rainfall, and to integrate the fog drip recharge occurring on the highest part of the volcano.

(ii) Hydroclimatological monitoring setup along the flank of the volcano enabled: (a) to determine the rainfall distribution (R); it peaks (4100 mm) at an elevation of about 1100 masl and then decreases back to the top of the volcano (1500 mm); (b) to compute real evapotranspiration (RET), and (c) then efficient rainfall (ER = R - RET). (d) Finally, the recharge rate is computed from hydrological measurements performed on a representative watershed (ER – runoff).

(iii) Finally, the local meteoric δ18O gradient is combined with the groundwater budget to fit jointly the steady-state discharge of the aquifer (discharge = recharge), and the isotopic signature of the Umbulan spring which is representative of the aquifer's δ18O groundwater, and is more than 50% of the total aquifer discharge.

This approach enables to precisely characterize the recharge/elevation relationships: in that case study, the aquifer recharge is mostly governed by the recharge rate distribution that is itself depending both on the efficient rainfall distribution, and the corresponding surface area that is decreasing upwards. About 75% of the aquifer recharge is infiltrating between 300 and 1300 masl and the remaining 25% above, up to the top of the volcano's flank. This result is consistent with field observations that show no significant hydrogeological change (only rather permeable unweathered lavic and pyroclastic rocks), between the upper limit of the low permeability volcanosedimentary rocks caping the volcanic aquifer (100 masl) and the top of the volcano. It also enables to delineate the West-East lateral extension of the aquifer's recharge area. These results allow to complete the first conceptual hydrogeological model of the Bromo-Tengger volcano.