Supplementary material: Identification test of recharge rate through a basaltic lava deposit (Harrat Al-Sham) in the Amman-Zarqa Basin (Jordan)

Al-Zyoud (2012) and Al-Zyoud et al. (2015) provided valuable hydrogeological data for the Harrat Al-Sham (Syria, Jordan, KSA; also called Al Harrah in KSA) which corresponds to the largest volcanic lava deposit of the Arabian Peninsula, partly extending over the Saq-Ram Aquifer System. The work of Al-Zyoud et al. (2012; 2015) focused chiefly on the geothermal exploitation of the Amman-Zarqa Basin (Jordan), but upon proper interpretation of the piezometric data provided, relevant information about the recharge through the basaltic deposits can be obtained.

This domain (4 500 km²) comprises two main aquifer formations: fractured and vesicular Pliocene basalts with high hydraulic conductivity (about 4×10^{-4} m s^{-1} according to hydraulic tests), and fractured Cretaceous limestones (B2/A7) with medium hydraulic conductivity (8×10^{-5} m s^{-1}). The volcanic lava deposits directly overlie the limestone formation forming a single fractured multilayer aquifer. Thus, the water table of this unconfined aquifer can be located in fact either in the overlying basalts or in the underlying limestone formation. However, the piezometric data of Al-Zyoud et al. (2015), combined with the geologic cross section provided, indicate that the water table is contained in the limestone formation.

The groundwater level variations can be interpreted in terms of seasonal recharge (R) through the basalts using the water table fluctuation method (Crosbie et al., 2005; Cuthbert, 2010; Healy and Cook, 2002; Seraphin et al., 2018). However, the specific yield (S_y) of the formation where the groundwater fluctuations occur (i.e. B2/A7 limestones) needs to be identified. Hydraulic tests conducted by Howard Humphreys Consulting Engineers (1986; reported in Khdier, 1997) gave a specific yield of 0.7% for a well located in the basalt/limestone area studied (Khaw Obs., 5 km northeast of Zarqa). The validity of this single and local value over the area studied by Al-Zyoud et al. (about 4 000 km^2) needs to be verified to enable the interpretation of the average piezometric record in terms of a domain-averaged recharge value. Using GRACE (Gravity Recovery and Climate Experiment) satellite data combined with piezometric monitoring S_y can be constrained at a larger scale. Therefore, the groundwater storage variation ΔGWS (m yr^{-1}) which can be inferred from GRACE data is related to the piezometric variation Δh (m yr^{-1}) by $\Delta GWS = S_y \times \Delta h$. The most widely exploited aquifer (almost exclusively) is B2/A7 which leads to an average piezometric drawdown Δh of -1.1 m yr^{-1} over the period 2000-2015 in the area (Amman-Zarqa basin, Al-Zyoud et al., 2015). GRACE data for the grid containing the study area (36°N-37°N, 32°E-33°E; CSR and JPL signal average, https://grace.jpl.nasa.gov/data-analysis-tool/) yield an average Terrestrial Water Storage variation (TWS) of -9.6 mm yr^{-1} over the period 2002-2015 which represents soil and groundwater variations. If we assume that the land water mass variation is mainly driven by groundwater loss ($GWS \approx TWS$; soil and surface water variations are low in comparison, which has been repeatedly observed in the Saharan climate domain; Gonçalvès et al., 2021; Mohamed et al., 2017; Mohamed and Gonçalvès, 2021; this study), we obtain a domain average value of $S_y = \Delta GWS / \Delta h = 0.87\%$ which is low but characteristic of a fractured aquifer (generally $S_y < 1\%$) and consistent with the only ground-based value.

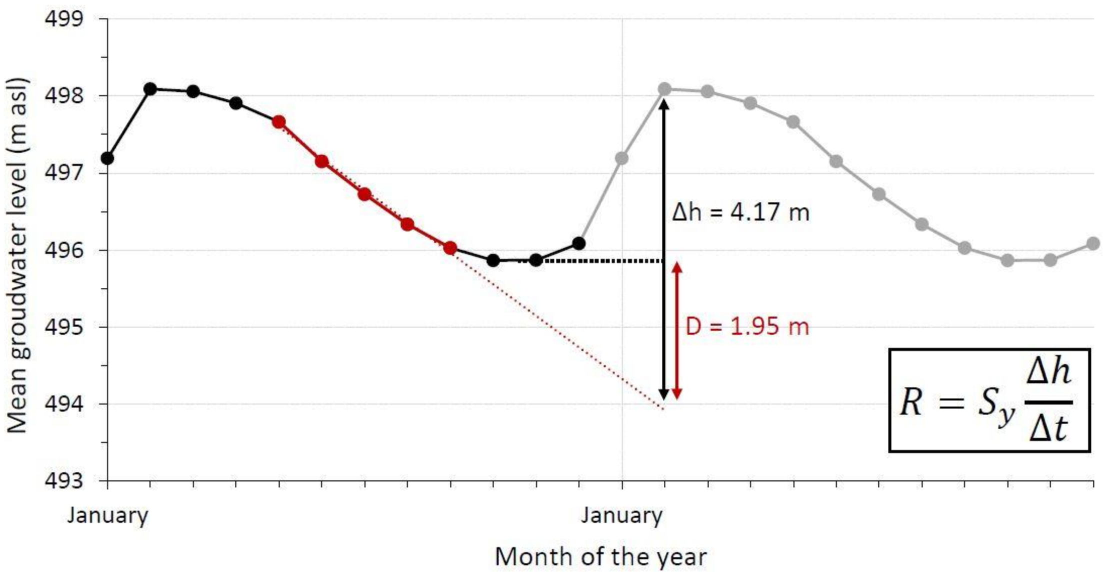

***Figure S1**: Groundwater signal monthly averaged over the 2000-2010 period (black line) for eight piezometers (Al-Zyoud et al., 2015) and duplicated (gray line) to estimate the annual recharge R (Δt = 1 year) using the regional piezometric rise Δh and the groundwater lateral drainage D identified during the dry period (red line).*

Although Al-Zyoud et al. (2015) provided groundwater signals until 2015, changes in the drawdown trend of some piezometers (probably due to an increase in local pumping) have been observed since 2010. The interpretation in terms of mean regional recharge is therefore limited to the 2000-2010 period. Thus, a water table fluctuation method was applied on the spatial (eight piezometers) and temporal (2000-2010 monthly signal) average of the seasonal groundwater signal as presented in Fig. 1. The regional annual piezometric rise (Δh; Figure S1), including the groundwater lateral drainage (*D*, natural plus drainage induced by pumping), yields 29 and 36 mm of annual average regional recharge (*R*) using 0.7 and 0.87% of specific yield (S_y) respectively. With an Average Annual Rainfall (AAR) of 115 mm between 2005 and 2011 (Al-Zyoud, 2012), this means that the recharge of the B2/A7 limestone, through the basaltic deposits of the Amman-Zarqa Basin, equals 29 ± 3% of AAR.

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