An ecohydrological journey of 4500+ years reveals a surprisingly stable precipitation-aquifer recharge relation in the Jerusalem region

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The analyses of ecosystem response to climatic variability have been primarily concentrated on the last decades, due mainly to the lack of long-term meteorological records. Here, we assessed long-term precipitation-aquifer recharge dynamics in the Jerusalem region by exploring a unique 4500 years reconstructed annual precipitation time series (Morin et al 2019) and proxy information on air temperature, solar radiation, and atmospheric CO₂ concentration [CO₂]. We combined these data to reconstruct continuous hourly time series of climatic variables from 2500 B.C. to present using a weather generator model. The reconstructed climatic variables were then used to force the T&C mechanistic ecohydrological model (Fatichi and Pappas, 2017). Simulation results quantified the change in groundwater recharge, a key variable for water resource management in the region, which is simulated as deep drainage from the soil profile. For the recent years, modeled vegetation dynamics were evaluated with remote sensing observations of Leaf Area Index (LAI) while modeled recharge was validated with observed discharge from a number of local springs. The 4500 years of simulations revealed that groundwater recharge was strongly affected by precipitation not only at the annual scale, as expected, but also by a multi-decadal average, suggesting an important memory effect of soil moisture conditions on recharge. Almost the entire variability in groundwater recharge over 4500 years was explained by precipitation alone, with minor effects of temperature and [CO₂], which both displayed significant changes in the last 50 years. The compensating biophysical and ecophysiological effects of [CO₂] increase on plants could explain this pattern: while an increase in [CO₂] stimulates productivity and LAI, increasing also evapotranspiration (ET) and decreasing recharge, it also improves water use efficiency, thus largely cancelling the aforementioned effect on ET. A sensitivity analysis to expected future levels of [CO₂] and temperature clearly showed that elevated CO₂ contributes to maintain current groundwater recharge values also in the future by closing stomata. However, a +2-3°C air temperature increase could reduce groundwater recharge of 30-40% due to enhanced ground evaporation and evaporation from interception, but also because of larger transpiration due to higher vapor pressure deficit, despite an enhanced plant water stress. The link between
groundwater recharge and precipitation in the Jerusalem region has been very stable in the last 4500 years, but this stability is jeopardized in a warmer future, with potentially strong implications for water resources management.
