Event based recharge assessment from soil moisture monitoring sites under a steep semi-arid climatic gradient

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Introduction and Objectives

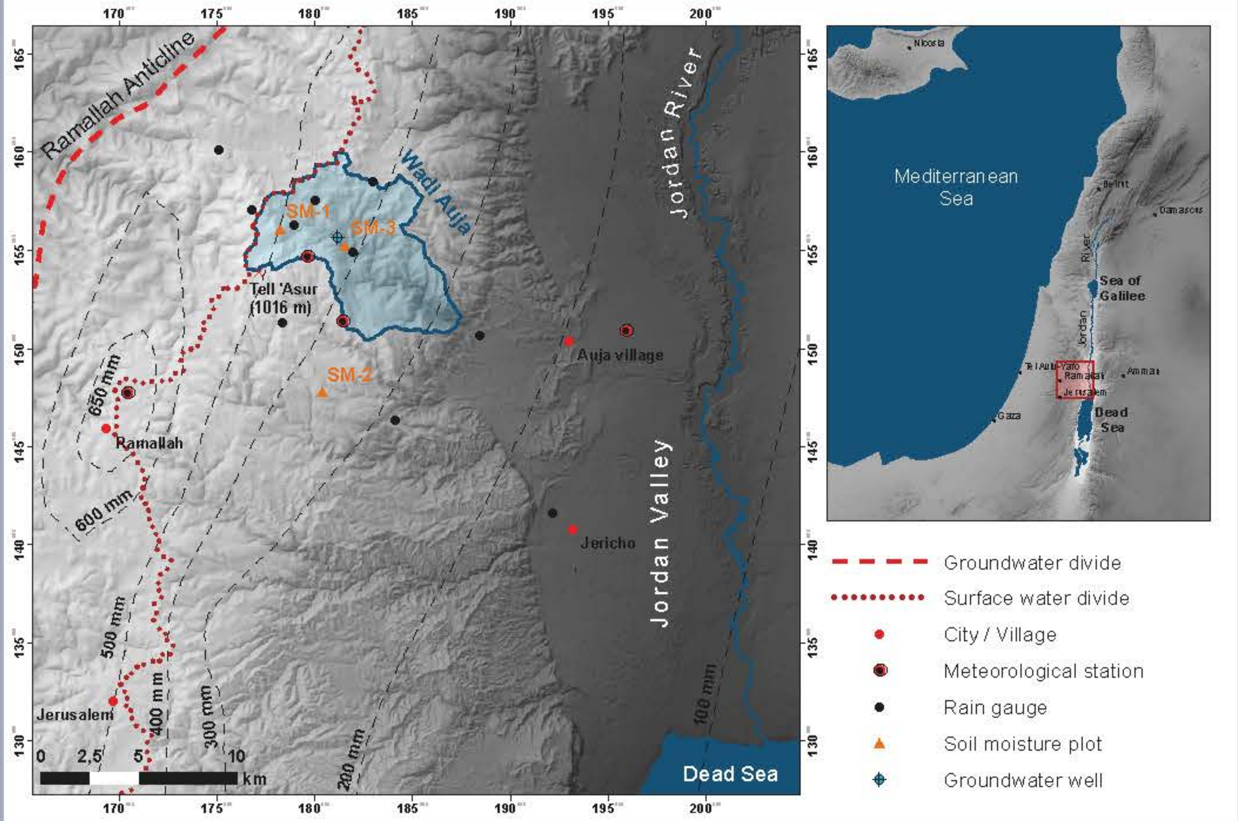
Groundwater recharge in Mediterranean karst areas is an important variable but afflicted with high spatial and temporal variability due to:

- Alternating rock outcrops and soil pockets of variable depth.
- Rainfall and climatic gradients.
- High annual variability of rainfall amounts and intensities.

The objective of this study is to:

1. Measure soil moisture at the plot scale
2. Model the unsaturated soil zone
3. Extrapolate to variable soil depth and climatic conditions

Study area



Map of the study area at the western escarpment of the Jordan Rift Valley (top); typical hillslopes in the study area (bottom).

Acknowledgements

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SMART

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Methods

1 Soil moisture dynamics

- Soil moisture measurements in different depths at three plots along the climatic gradient.
- Terra rossa soils with profile depths between 50 and 100 cm.
- Soil moisture data was corrected for temperature effects on dielectric permittivity by linear regressions.

Plot	Elevation (m a.s.l.)	Mean annual rainfall[1] (mm)	Soil depth (cm)	Sensor depths (cm)	Vegetation
SM-1	810	526	100	10, 25, 40, 80	Mediterranean shrubs; annual plants
SM-2	660	340[2]	50	5, 10, 20, 35	Annual plants
SM-3	440	351	60	5, 10, 20, 35	Annual plants

[1] Mean rainfall calculated based on three winter seasons (2010-2013)
[2] Rainfall at plot SM-2 is estimated by inverse distance weighted interpolation with elevation as additional predictor

Soil moisture plot characteristics.

2 Unsaturated zone modelling

- Hydrus-1D modelling with Mualem/van-Genuchten soil hydraulic model and an air entry value of 2 cm.
- Etp calculations according to Hargreaves.
- Seasonal vegetation cover with maximum development in February/March after highest monthly precipitation amounts and exponential decrease of root density with depth.
- Soil hydrauliy parameters for every soil material were calibrated by inverse modelling with Shuffled Complex Evolution Algorithm (SCEM) and Kling-Gupta efficiency as objective function.
- Gelman-Rubin convergence criteria (parameter uncertainty from 1000 runs after convergence).

3 Extrapolation

- Spatial extrapolation by variing soil depth (10 cm to 200 cm) and rainfall input along the semi-arid climatic gradient (climatic conditions between 400 and 1000 m a.s.l.).
- Temporal extrapolation by applying the model to a 62-years period with available data of rainfall and temperature at Jerusalem station.

Conclusion

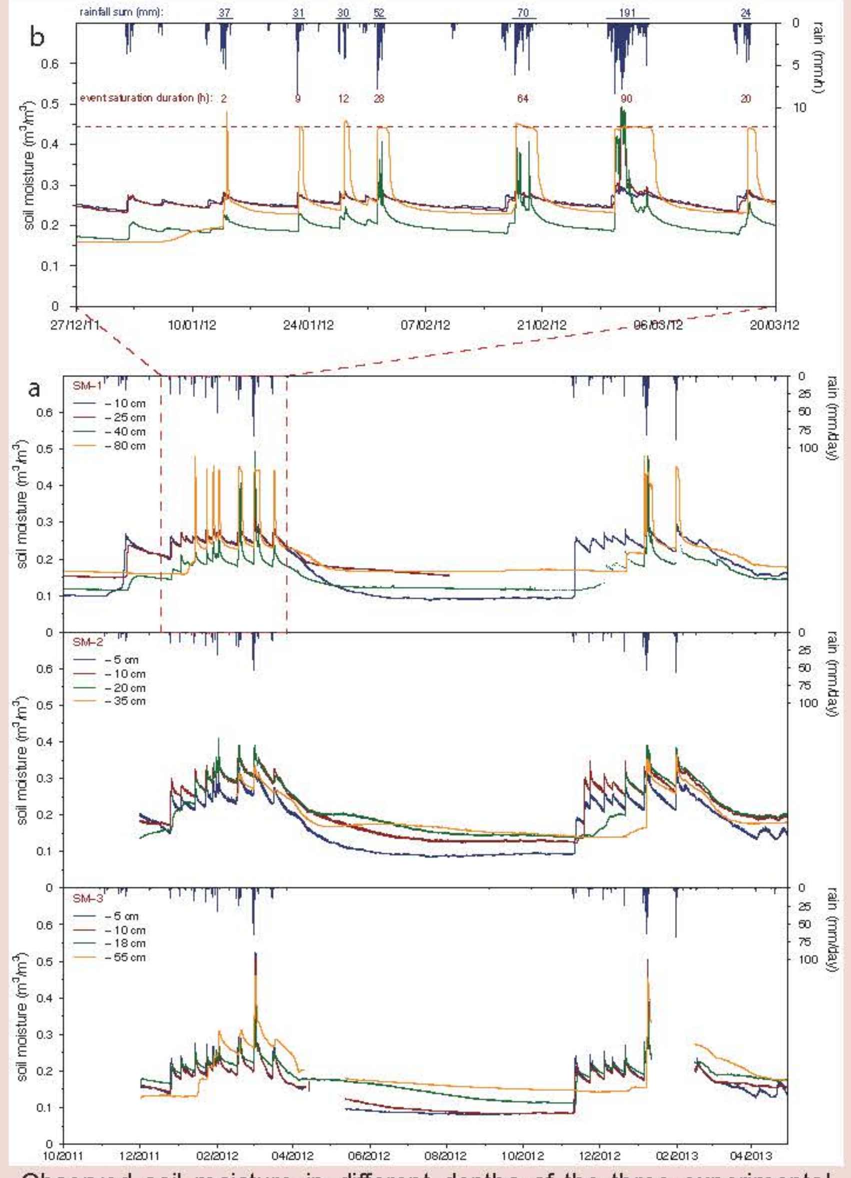
Soil moisture observations reflect the strong seasonality of soil moisture. During high magnitude rainstroms fast infiltration caused saturated conditions at the bottom of the soil profile.

Numerical modelling nicely reproduced the observed soil moisture patterns. Results suggested that percolation depended on rainfall thresholds and was limited to the strongest rainfall events.

Extrapolation of the calibrated model resulted in a strong dependency of percolation on soil depth along the climatic gradient. A 62-year water balance showed mean annual percolation between 20% to 28% and up to a two-fold difference in percolation for years with same seasonal rainfall but different distribution.

Results

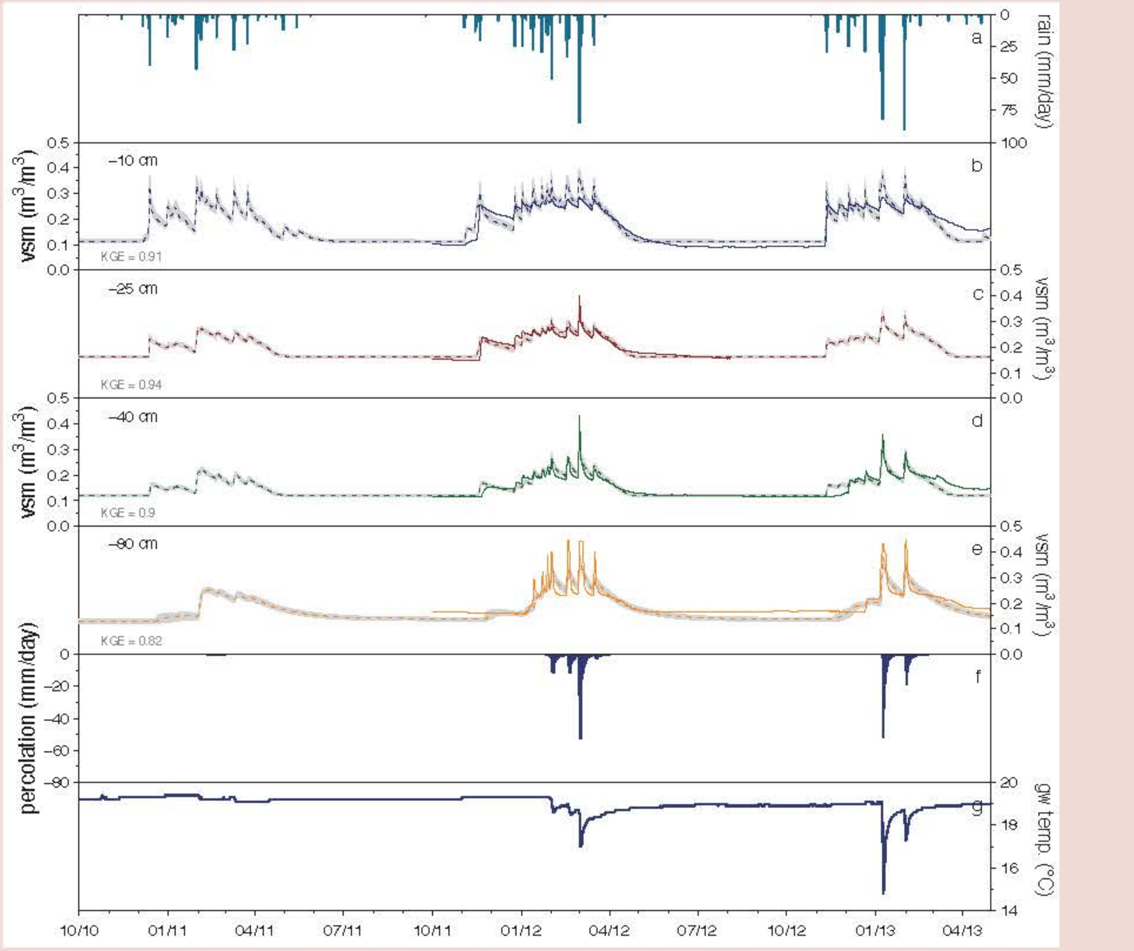
1 Soil moisture dynamics



Observed soil moisture in different depths of the three experimental plots over the monitoring period (a) and details on the winter season 2011/2012 for plot SM-1 (b).

- Strong seasonality of soil moisture.
- Fast infiltration and percolation (less than two hours to reach the bottom of the profile).
- Saturated conditions at the soil-bedrock interface during high intensity storms at plot SM-1 and SM-3.
- Cumulative rainfall thresholds to reach saturated conditions are between 150 and 240 mm.

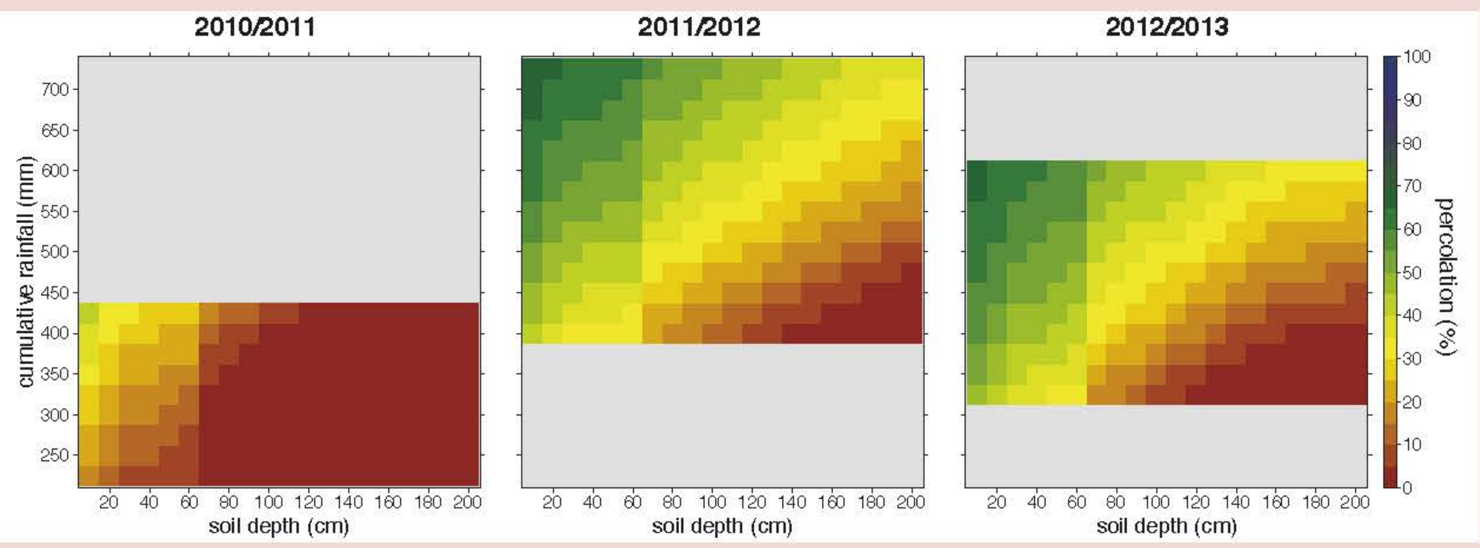
2 Plot scale model results



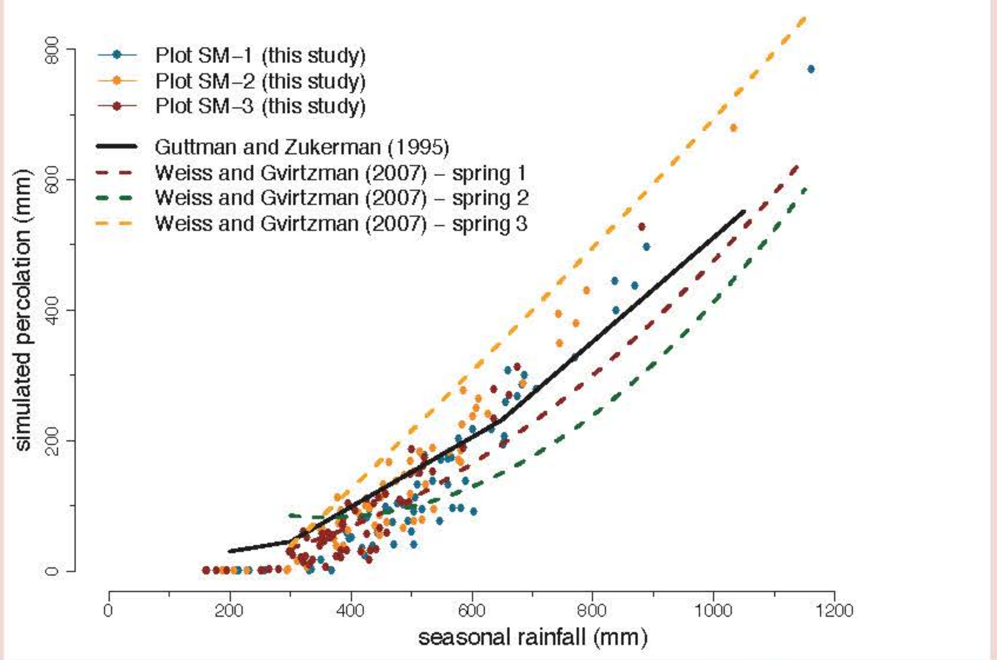
Time series of rainfall (a), simulated and observed volumetric water content for soil moisture plot SM-1 (b-e), Hydrus-1D simulated percolation (f) and water temperature in a nearby groundwater well (g). The grey shaded area represents the 95 % confidence interval of simulated soil moisture

- More than 50 % of overall percolation fluxes occurred in less than 10 days of strong rainfall
- Percolation peaks supported by groundwater temperature data

3 Spatial and temporal extrapolation



Simulated percolation in relation to soil depth and rainfall amounts along the climatic gradient for three consecutive winter seasons with different rainfall amounts and distribution patterns. Simulations were based on calibrated soil hydraulic properties of plots SM-1. The grey shaded area display rainfall amounts, which have not been reached in the study area within altitudes of 400 to 1000 m a.s.l. according to calculated rainfall gradients.



Simulated seasonal percolation at the plot scale (SM-1, SM-2, SM-3) for the period 1951-2013 in comparison with rainfall-recharge relationships for the carbonate aquifer (Guttmann and Zukerman, 1995) and three small karst springs emerging from local perched aquifers (Weiss and Gvirtzman, 2007).

- Overall amount and thresholds for the initiation of percolation depend strongly on soil depth, seasonal amount and temporal distribution of rainfall.
- Percolation rates range between 0% and 69% of seasonal rainfall.
- Groundwater recharge is highest when single rainfall events are strong enough to exceed field capacity of soil pockets over a wide range of soil depths.

- The simulated mean annual percolation of 20% to 28% for our plots are in good agreement with recharge culations based on karst springs in the area.
- Percolation can differ strongly in years with the same rainfall amount but different distribution.

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