Comparison of methods to calculate groundwater recharge for the karstic Western Mountain Aquifer

Key findings

- We calculate groundwater recharge for the Western Mountain Aquifer with the Soil & Water Assessment Tool (SWAT) and a soil water balance model (SWBM). The results are compared with two established empirical methods by Zukerman (1999) and Abusaada (2011).
- While Zukerman and the SWBM calculate higher recharge in wet years, Abusaada and the SWAT model calculate higher recharge in years with average to low precipitation.
- The estimated average annual recharge ranges between 30% (SWBM) and 34.7% (Abusaada) of annual precipitation.

Motivation

Recharge is the most important input factor of groundwater models. It occurs in the outcrops of the karstic Western Mountain Aquifer (WMA) in Israel and the West Bank at different rates due to a dual-type flow system comprising conduit flow (fast flow component) and diffuse infiltration (slow flow component). Recharge is not only determined by surface properties but also by the distribution of precipitation throughout the year. The Soil & Water Assessment Tool (SWAT) addresses this problem and calculates daily recharge rates on a small spatial scale. A similarly high spatial and temporal resolution can be achieved with the application of a soil and water balance model (SWBM). Standard empirical equations are used traditionally to calculate recharge with one set of equations without considering spatial differences or the influence of extreme weather events. Here, we compare the recharge estimates from a SWAT model and a SWBM to those calculated with two established empirical methods.

Methodology

Recharge estimates from a SWAT model were compared to recharge rates calculated with the empirical methods by Abusaada (2011) and Zukerman (1999). While SWAT calculates the water balance with daily climate data and therefore takes into account the influence of extreme precipitation events and potential over-saturation of the soil, the empirical methods only use monthly (Abusaada) or annual (Zukerman) precipitation amounts. As Abusaada assumes that recharge occurs mostly during the wet months of November – March, he specifically developed a set of equations for these months. Zukerman on the other hand developed equations for different annual precipitations, assuming the percentage of precipitation resulting in groundwater recharge increases with greater annual precipitation. In addition, we applied a SWBM by Schmidt et al. (2014) to calculate the percolation at the zero-flux plane with soil water balance equations. The method uses the same temporal and spatial distribution as the SWAT model and the same precipitation and potential evapotranspiration data. Recharge is calculated for the hydrological year September – August and based on the same climate data (Israel Meteorological Service (IMS)).

Recharge estimation

Recharge rates for the WMA are estimated with different methods: empirical equations by Zukerman (1999) and Abusaada (2011) as well as a SWAT model and a SWBM. While the empirical methods only use monthly or annual precipitation data averaged over the entire recharge area, SWAT, for example, requires additional information about temperature, solar radiation, relative humidity, and wind velocity as well as soil and topography.

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Results

The recharge comparison for the period 1979-2019 shows an average annual recharge of 173-201 mm per year (Table 1). The percentage of mean annual precipitation (576 mm) resulting in groundwater recharge is between 30 and 34.7%. The highest recharge is calculated with Abusaada's equation and the SWAT model, while the SWBM calculates the lowest recharge. Figure 1 shows the annual precipitation and recharge calculated with the four methods. During the extremely wet years 1991, 1992, and 1994, Zukerman's equation and the SWBM calculate the highest recharge, while they underestimate recharge during years with average precipitation compared to Abusaada. For wet years, the SWAT model and Abusaada's equations do not calculate the high peaks found in the Zukerman and SWBM results. The extremely dry years of 1999 and 2017 on the other hand resulted in below-average recharge calculated with Abusaada's equation and the SWAT model. Overall, the SWAT model shows the same correlation between annual precipitation and recharge as Abusaada's equation, while the SWBM and Zukerman's equation provide similar results (Figure 2).

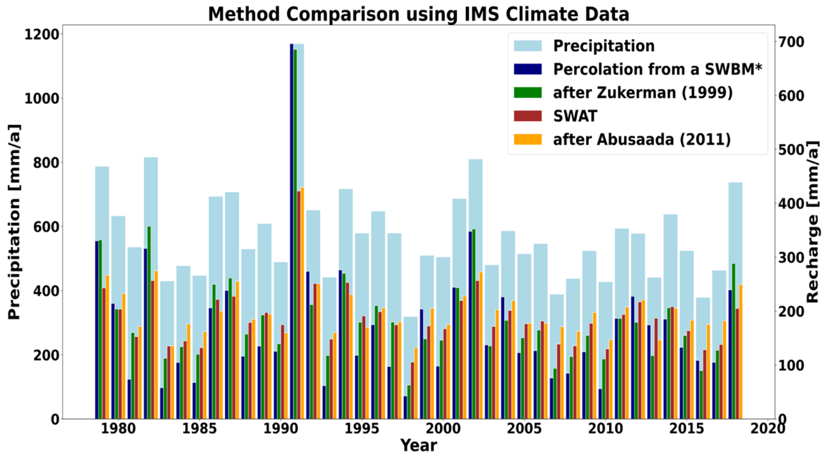

Figure 1: Precipitation and recharge from 1979-2018. *SWBM: soil water balance model.

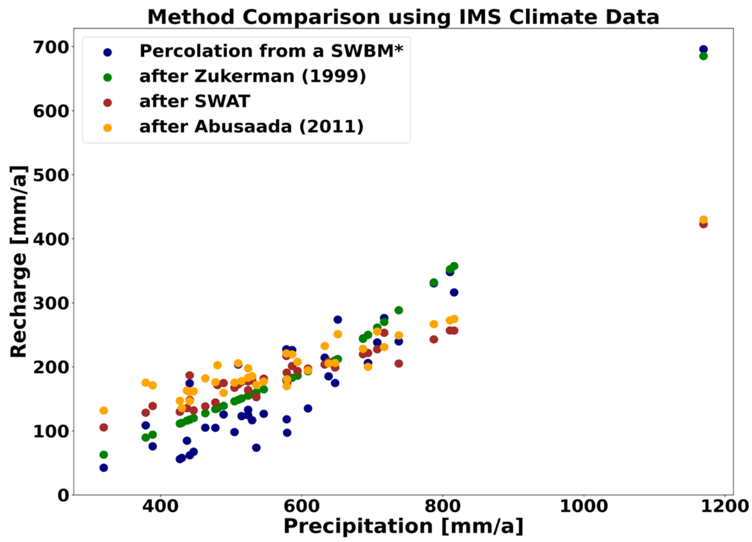

Figure 2: Scatter plot of annual precipitation and recharge. *SWBM: soil water balance model.

Method	mm/a	Mm³/a	%
SWAT	199	360	34.5
SWBM	173	314	30,0
Abusaada	201	364	34.7
Zukerman	192	348	33,2

Table 1: Average annual recharge in mm/a, Mm³/a, and in % of average annual precipitation

Application

Calculating recharge in a highly karstified aquifer is challenging but of great importance due to its comparatively lower storage potential. This makes karst aquifers highly vulnerable to potential decreases in precipitation and recharge caused by climate change. Identifying and applying the most accurate method for recharge estimation is very important for future management of the Western Mountain Aquifer and to better assess the volume of stored water. All compared methods have benefits: While the equations by Zukerman and Abusaada are easy to apply, the spatial and temporal distribution of recharge is only simulated with SWAT and the SWBM. This can be a major benefit for regional management purposes.

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