Hydro-Pedo-Transfer Functions (HPTFs) for prediction of groundwater recharge in karst aquifers under Mediterranean climate

Key findings

- Mean annual percolation in the study area is primarily dependent on precipitation and potential evapotranspiration and only then determined by land cover and soil properties.
- The application of HPTFs to karst aquifers indicates that the functions cannot capture the rapid flow component of percolation and consequently underestimate recharge.
- However, if this rapid flow component is available from other models, the association with infiltration data from HPTFs yields suitable results for groundwater recharge estimations.

Motivation

Groundwater resources are crucial for the supply of freshwater in the Mediterranean region. Understanding the processes that control groundwater recharge is of vital importance to meet present and future challenges. Especially in karst systems, recharge processes are complex and diverse. This study quantifies groundwater recharge for the Western Mountain Aquifer (WMA) in Israel and the West Bank by extending the application of Hydro-Pedo-Transfer Functions (HPTFs) to the Mediterranean climate and karst aquifers. So far, their application is limited to the Continental European climate. Mediterranean climate in contrast is characteristic of two distinct seasons: hot, dry summers and mild, rainy winters. In addition, soil cover and vegetation patches on karst surfaces are highly variable. These aspects are expected to have considerable effect on infiltration and the replenishment of karst aquifers. Only limited input data is required when applying HPTFs. Thus, the functions can be used despite possible data scarcity.

Methodology

The recharge area of the WMA is the model area of this study. HPTFs are based on annual calculations of the water balance in flat topography. The functions depend on the type of land cover and account for annual and seasonal precipitation, potential evapotranspiration, and soil water in the effective root zone. These parameters are correlated within a Geographic Information System (GIS) before applying them to the empirical functions (Table 1). Remote sensing and global data sets are being used, which are most feasible for providing temporally and spatially continuous information when working on a regional scale. Precipitation patterns in the Mediterranean climate are subject to a high natural variability, and extreme values of evapotranspiration exceed rainfall during most days. The appli cation of HPTFs to groundwater-recharge estimations in the study

Table 1 : Applied HPTFs in the study area to predict annual percolation rate (D_a) for four different types of land cover after Wesolek et al. (2008) with P_a: annual precipitation, PET: potential evapotranspiration, W_a: plant-available soil water in the effective root zone, and P_s: precipitation during the vegetation growth period. Capillary rise (Q) is set to zero in the study area due to groundwater tables far below the root zone.

Cropland

$D_a = P_a - PET\ (1.45 \log (W_a + Q + P_s) - 3.08)\ (0.685 \log (1/PET) + 2.865)$

Grassland

$D_a = P_a - PET\ (1.79 \log (W_a + Q + P_s) - 3.89)\ (0.53 \log (1/PET) + 2.43)$

Forest

Coniferous:

$D_a = P_a - PET\ (1.68 \log (W_a + Q + P_s) - 3.53)\ (0.865 \log (1/PET) + 3.36)$

Deciduous:

$D_a = P_a - 0.9\ PET\ (1.68 \log (W_a + Q + P_s) - 3.53)\ (0.865 \log (1/PET) + 3.36)$

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Hydro-Pedo-Transfer Functions (HPTFs)

Hydro-Pedo-Transfer Functions (HPTFs) were first introduced by Wessolek et al. (2008) following Lin's (2003) "Hydropedology" approach – the integration of methods from soil, plant, and water science. HPTFs predict annual percolation rates on a regional scale under various types of land cover including cropland, grassland, and coniferous and deciduous forests. The empirical functions are based on the water budget equation and account for annual precipitation, potential evapotranspiration, soil properties, and vegetation.

area is limited to the winter months (Dec.-Feb.), when 60 to 90% of annual rainfall occur. The study period is set from 2001 to 2015 due to the availability of consistent datasets. The soil properties for this time are considered unchanging.

Results

The spatial and temporal distribution of percolation in the recharge area of the WMA is calculated for each grid cell (500x500 m resolution) and visualized in annual percolation maps (Figure 1). The functions predict a mean annual percolation of 72 mm, representing on average 19% of the mean rainfall from December to February and 15% of the long-term mean annual rainfall. Previous studies estimate recharge to be 25-35% of the mean annual precipitation for average years. The calculated infiltration values for each cell are summed up over the entire model domain to obtain annual groundwater recharge values. HPTFs assume a spatially uniform replenishment of the aquifer and that all water that passes the root zone reaches the groundwater reservoir. The resulting estimates are shown in Figure 2. Recharge estimates from given spring discharge and pumping rates are also depicted for validation. Mean annual recharge is estimated at 94 Mm³ compared to 355 Mm³ of spring discharge and pumping rates. It is evident that the total amount of recharge is highly underestimated. High-intensity rainfall events, frequently occurring during the rainy season, may rapidly infiltrate into exposed karst surfaces and induce high recharge. Averaging over longer time periods clearly dampens out these effects.

Application

This study estimates the mean annual percolation in the WMA's recharge area and its spatial distribution using HPTFs. It shows that the functions are not able to capture the rapid flow component, highly relevant for infiltration in karst, and thus underestimate recharge. Field investigations of topographic features such as sinkholes or highly fractured zones might enable the adaptation of the functions in certain areas to account for rapid flow components of recharge in karst groundwater systems. An accurate estimation of actual evapotranspiration is of key importance. Additionally, the characteristics of Mediterranean climate (distinct dry and wet seasons) challenge an application of HPTFs for long time periods. The feasibility of water budget approaches in semi-arid regions is subject to ongoing research.

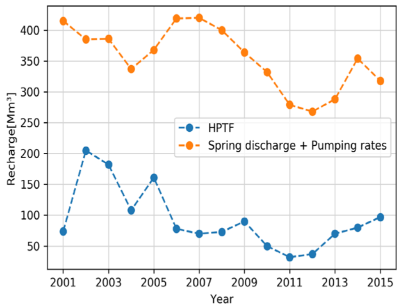

Figure 2: Estimated groundwater recharge for the WMA using HPTFs (mean: 94 Mm³) in comparison to available pumping rates and data on spring discharge (mean: 355 Mm³). Recharge predictions are highly underestimated, indicating that the functions are not able to capture the rapid flow component of infiltration in karst.

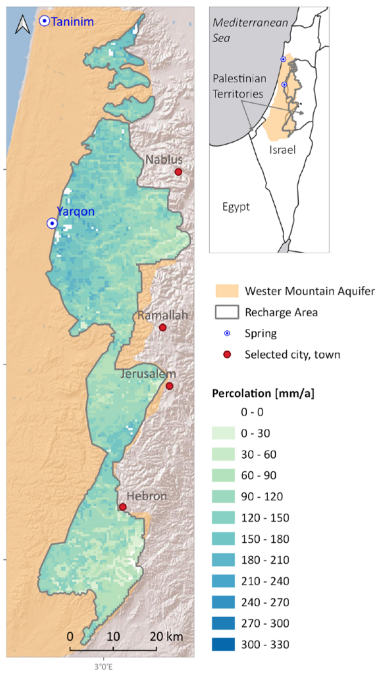

Figure 1: Spatial distribution of mean annual percolation in the WMA's recharge area in 2002. A general north to south trend of decreasing percolation is caused by a strong gradient in precipitation. Zero percolation (white grid cells) is indicated in the urban metropolitan region of Tel Aviv-Yafo. Resolution: 500x500 m.

References

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