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# Vadose zone lag time effect on groundwater drought propagation in a temperate climate

Buruk Kitachew Wossenyeleh (1), Boud Verbeiren (2), Jan Diels (1), Marijke Huysmans (1,2)

(1) Department of Earth and Environmental Sciences, KU Leuven University, Leuven, Belgium, (2) Department of Hydrology and Hydraulic Engineering, Vrije Universiteit Brussel, Brussels, Belgium

An essential factor in the propagation of drought from meteorological drought to groundwater drought is the delay between a precipitation event and the groundwater recharge reaching the groundwater table. This delay mainly occurs in the unsaturated soil zone of the hydrological cycle. However, studies of drought propagation in the hydrological cycle often neglect these lag effects caused by the vadose zone. Additionally, this effect is often not considered in groundwater modelling, analysis of climate change impact on groundwater, and the effective management and sustainability of future water resources.
This research aims to estimate the spatially distributed vadose zone lag time in relation to drought propagation using the kinematic wave approximation of Richards' equation under the assumption of deep drainage occurring in response to rainfall infiltration, steady vertical flow (no flow barriers or artificial drainage), and isotropic and homogenous soil hydraulic properties. This theory is combined with the van Genuchten-Burdine and Brooks-Corey parametric models. This research is carried out in the Dijle and Demer catchments in central Belgium, which overly the vulnerable Brulandtkrijt and Central Campine groundwater systems.
In this research, two approaches are implemented for groundwater recharge delay estimation for both van Genuchten-Burdine and Brooks-Corey parametric models. In the first approach, a detailed parametrization of soil and geological layers was obtained based on 168 borehole descriptions. In the second approach, lumped hydraulic and physical properties were used for a limited number of soil and geological layers. The results of both parametric models from both approaches were validated using the physical based flow model Hydrus-1D. As the result, detailed parametrization of soil and geological layers gives good validation result with a Nash-Sutcliffe Efficiency of 0.89 for Brooks-Corey and 0.80 for van Genuchten-Burdine.
Under consideration of detailed parametrization of soil and geological layers, the estimated spatially distributed groundwater recharge delay in the vadose zone using the Brooks-Corey model ranges from 0 to 110 months, with a spatial mean of 10.3 months. Using the van Genuchten-Burdine model the delay ranges from 0 to 73 months with a spatial mean of 6.7 months. The thickness of the vadose zone is the main parameter influencing the spatial distribution of this delay. In regions with shallow groundwater mostly found in the northern part of the study area, groundwater recharge delay is less than 2 months whereas the delay is up to 110 months for the areas found in the southeast with deep water tables.
This delay is combined with the groundwater recharge time series to compare the result with meteorological drought. This is done by comparing the time series of standardized precipitation index (SPI) with the delayed recharge.
Finally, the result of the two models and approaches are compared. The Brooks-Corey model using a detailed parametrization of the geological layers results clearly shows groundwater drought in recharge occurred after meteorological drought.

Keywords: Groundwater Drought, Groundwater Recharge Delay, Vadose zone, Kinematic wave approximation