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A Monte Carlo approach for improved estimation of groundwater level spatial variability in poorly gauged basins

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Groundwater level is an important source of information in hydrological modelling. In many aquifers the boreholes monitored are scarce and/or sparse in space. In both cases, geostatistical methods can help to visualize the free surface of an aquifer, whereas the use of auxiliary information improves the accuracy of level estimates and maximizes the information gain for the quantification of groundwater level spatial variability. In addition, they allow the exploitation of datasets that cannot otherwise be efficiently used in catchment models.
In this presentation, we demonstrate an approach for incorporating auxiliary information in interpolation approaches using a specific case study. In particular, the study area is located on the island of Crete (Greece). The available data consist of 70 hydraulic head measurements for the wet period of the hydrological year 2002-2003, the average pumping rates at the 70 wells, and 10 piezometer readings measured in the preceding hydrological year. We present a groundwater level trend model based on the generalized Thiem's equation for multiple wells. We use the drift term to incorporate secondary information in Residual Kriging (RK) (Varouchakis and Hristopulos 2013). The residuals are then interpolated using Ordinary Kriging and then are added to the drift model.
Thiem's equation describes the relationship between the steady-state radial inflow into a pumping well and the drawdown. The generalized form of the equation includes the influence of a number of pumping wells. It incorporates the estimated hydraulic head, the initial hydraulic head before abstraction, the number of wells, the pumping rate, the distance of the estimation point from each well, and the well's radius of influence. We assume that the initial hydraulic head follows a linear trend, which we model based on the preceding hydrological year measurements. The hydraulic conductivity in the study basin varies between 0.0014 and 0.00014 m/s according to geological estimates. Since pumping tests are not available, we determine the radius of influence using an empirical equation (Bear 1979) that involves the drawdown at the well face, the hydraulic conductivity around the pumping well, and the initial saturated thickness. Since the local variation of the drawdown and the hydraulic conductivity is not known, we use uniform values based on the Monte Carlo analysis below. The initial saturated thickness for all 70 wells is assumed to follow a linear trend estimated from the 10 piezometer readings and from the geological cross-sections available for the basin.
Using linear regression analysis of the mean annual groundwater level, we estimate the rate of mean annual level decrease at 1.85 m/yr, with the 95% confidence interval at [1.60-2.10] m/yr. The optimal hydraulic conductivity over the drawdown and the hydraulic conductivity parameter space is determined by means of Monte Carlo sensitivity analysis and leave-one-out cross validation that focus on the reproduction of the measured head values. The removed head values during the validation procedure are estimated using RK. The mean absolute error (MAE) is used as the criterion of optimal performance. The hydraulic head trend function is estimated for each combination of the hydraulic conductivity and the drawdown. The residuals are modeled using several semivariogram models for each realization of the hydraulic conductivity and the drawdown tested.
The Monte Carlo simulations show that the MAE is primarily sensitive to the variation of the hydraulic conductivity and less to the drawdown. The minimum MAE is obtained for a hydraulic conductivity of 0.00015 m/s and a drawdown equal to 1.85 m. The recently proposed Spartan semivariogram models for the residuals provide the most accurate estimates. Based on the above procedure, the range of the radius of influence is determined between 105 m and 160 m. The approach described above improves the MAE by 14% and the RMSE by 10% compared to similar approaches studied herein i.e. RK with a Digital Elevation Model of the area and the distance of the estimation point from the temporary river crossing the basin.

Bear, J., 1979. Hydraulics of groundwater. New York: McGraw-Hill.
Varouchakis, E. A. and Hristopulos, D. T. 2013. Improvement of groundwater level prediction in sparsely gauged basins using physical laws and local geographic features as auxiliary variables. Advances in Water Resources, 52, 34-49.