Recharge heterogeneity and high frequency rainfall events increase contamination risk for groundwater resources

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**Motivation**

Karst develops through the dissolution of carbonate rock. Karst groundwater in Europe is a major source of fresh water contributing up to half of the total drinking water supply in various countries. Previous work showed that the karstic preferential recharge processes result in enhanced recharge rates and potentially to more available groundwater for development. But as there is fast water flow from the surface to the aquifer, there is also an enhanced risk of groundwater contamination.

In this study, we quantify the contamination risk of karstic groundwater recharge with virtual tracer experiments.

**Methodology**

**Study area & data**

Since calibration data is not available at the regional scale, we used cluster analysis (K-means methods) and those climate and relief descriptors (aridity index A, days of snow DS, range of attitudes within the grid cell B) to define typical karst landscapes.

**Simulation approach**

We simulate groundwater recharge with a semi-distributed model that considers the spatial heterogeneity of the karst system by distribution functions. A newly developed parameter estimation scheme is applied to derive parameter sets and remaining parameter uncertainty for each of the karst landscapes using SWAT (Hedman) and soil moisture (SMO) observations for 2002-2012.

**Results**

Transit time distributions of simulated recharge are derived by applying a virtual tracer at each grid cell's precipitation with hydrological age. The time when recharge concentration of a model compartment reaches 50% of the input concentration is considered as main transit time. All mean transit times form the transit time distribution. For our analysis of vulnerability we calculate the fractions of young water (transit time 1-3 months).

**YOUNG WATER FRACTIONS OF GROUNDWATER RECHARGE**

The young water fractions (≤1.8 months) obtained by virtual tracer experiments cover a wide range of values. Low fractions of young water are found at the Mediterranean regions, while generally higher values are found at the Mediterranean.

**Simulated young water fractions (≤1.8 months)**

Comparison with young water fractions derived from time series of observed water isotopic composition at 88 karst springs across Europe show similar patterns as the simulation using either 1.6 or 3 months as threshold to define young water.

**Total volumes of groundwater recharge**

The simulations show high annual recharge rates in Northern Europe and the high mountain areas, very low values occur for Southern Europe and Northern Africa. The parameter uncertainty due to the limited data availability remains low in most of the study domain.

**Climatic controls**

We find the strongest significant relation (p<10%) between young water fractions and the number of winter events (≥10 mm) and the difference between rainfall events (p<0.05), the aridity index (p<0.01) and mean annual precipitation (p<0.05) for the Mediterranean regions. While in the other regions no such distinct patterns are visible. When recharge processes are turned off (uniform subsurface, no lateral flow concentration), young water fractions reduce drastically everywhere.

**Synthesis**

Transit time distributions have proven to be a valuable tool for contaminant risk assessment. We show that they can also be applied on a larger scale where simulation approaches have been focusing on water quantity estimations. To increase reliability stricter evaluation with water isotope data of karst springs is necessary.