Recharge heterogeneity and high frequency rainfall events increase contamination risk for Mediterranean 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.

STUDY AREA & DATA

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

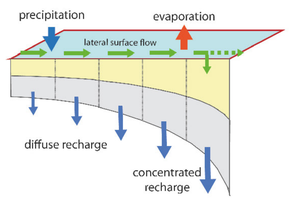
Descriptor	Unit	Number of cluster/karst landscape			
		1. HUM	2. MTN	3. MED	4. DES
AI	[-]	0.80	0.98	3.18	20.00
DS	[a^{-1}]	85	76	16	1
RA	[m]	228	1785	691	232

By trial and error (elbow method) we found 4 landscapes with distinct climatic and topographic characteristics: **HUM**id, MouNTain, **DES**ert and **MED**iterranean

The data for cluster analysis and model forcings (2002-2012) are obtained from SRTM3 and GLDAS.

SIMULATION APPROACH

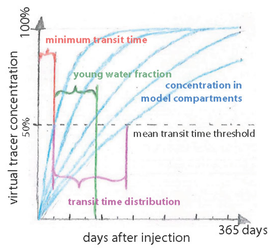
VarKarst-R model



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 AET (Fluxnet) and soil moisture (ISMN) observations for 2002-2012.

More details in Hartmann, A., Gleeson, T., Rosolem, R., Pianosi, F., Wada, Y. and Wagener, T.; Geosci. Model Dev., 8(6), 1729–1746, doi:10.5194/gmd-8-1729-2015 (2015).

Derivation of young water fractions



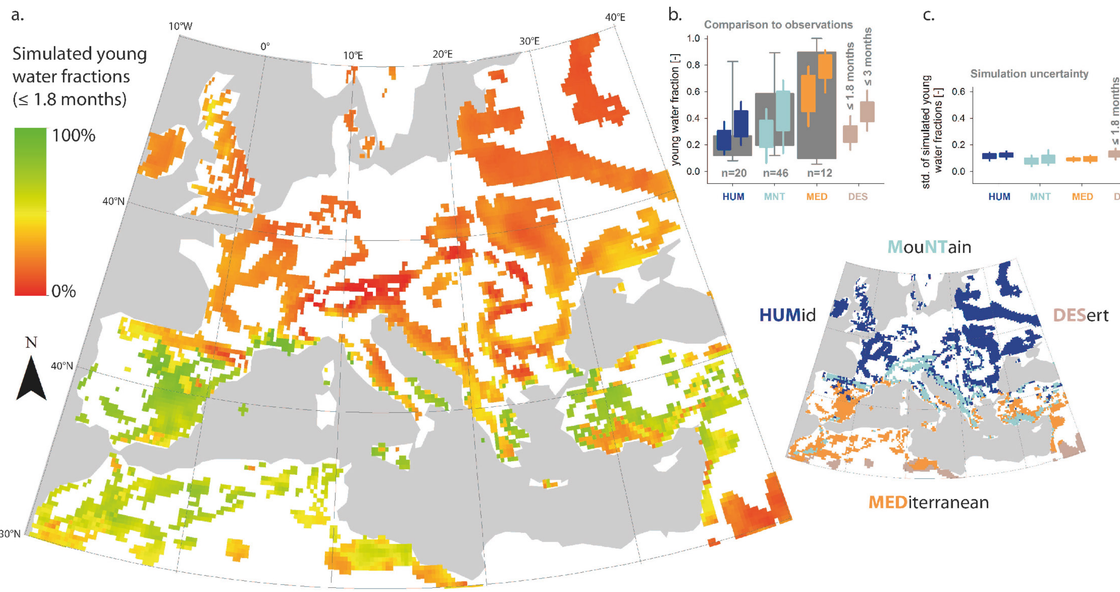
Transit time distributions of simulated recharge are derived by applying a virtual tracer at each grid cell's precipitation each hydrological year. The time when the recharge concentration of a model compartment reaches 50% of the input concentration is considered as mean transit time. All mean transit times form the transit time distribution. For our analysis of vulnerability we calculate the fractions of young water (transit time ≤ 1.8 - 3 months).

More details in Hartmann, A., Kobler, J., Kralik, M., Dirnböck, T., Humer, F. and Weiler, M.; Biogeosciences, 13, 159-174, doi:10.5194/bg-13-159-2016 (2016). **And** Kirchner, J.W.: Aggregation in environmental systems – Part 1: Seasonal tracer cycles quantify young water fractions, but not mean transit times, in spatially heterogeneous catchments, Hydrol. Earth Syst. Sci., 20, 279–297, doi:10.5194/hess-20-279-2016 (2016).

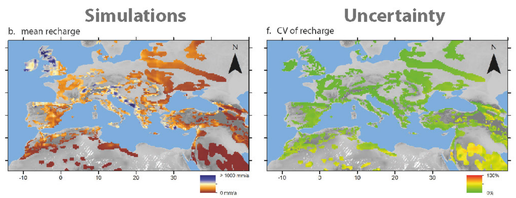
YOUNG WATER FRACTIONS OF GROUNDWATER RECHARGE

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

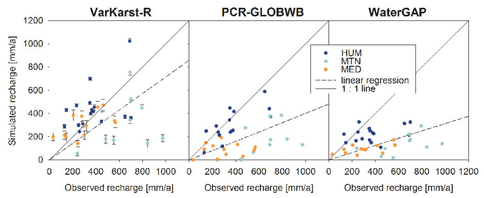
Comparison with young water fractions derived from time series of observed water isotopic composition at 88 karst springs across Europe show similar pattern as the simulation using either 1.8 or 3 months as threshold to define young water.



TOTAL VOLUMES OF GROUNDWATER RECHARGE

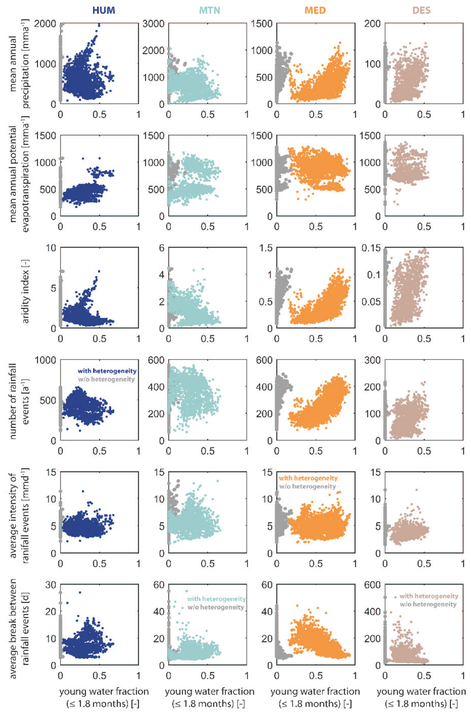


The simulations show high annual recharge rates in Northern Europe and in the high mountain areas, very low values occur for Southern Europe and Northern Africa. The paramater uncertainty due to the limited data avilability remains low in most of the study domain.



Comparison with independently obtained recharge volumes (review of experimental and modelling studies) shows that the simulations of the VarKarst-R model plot around the 1:1 line. Other established models tend to under-estimation, in particular at the MTN and HUM regions.

CLIMATIC CONTROLS



We find the strongest significant relation ($p<10^{-5}$) between young water fractions and the number of rainfall events (r=0.76), the average break between rainfall events (r=0.73), the aridity index (r=0.71) and mean annual precipitation (r=0.60) for the Mediterranean region. While at the other regions no such distinct pattern occurs. When heterogeneity 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 contamination risk assessment. We show that they can also be applied on a larger scale where simulation approaches have been focussing on water quantity estimations. To increase reliability stricter evaluation with water isotope data of karst springs is necessary.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