Enhanced recharge rates and a greater sensitivity to climate variations in regions with heterogeneous subsurface

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In hydrology, subsurface heterogeneity exerts an important control on water balance. This notably includes groundwater recharge, which is an important factor for efficient and sustainable groundwater resource management. Currently, large-scale hydrological models do not adequately consider subsurface heterogeneity.

We show that regions with strong subsurface heterogeneity have enhanced recharge rates and greater sensitivity to future climate variability compared to regions with homogeneous subsurface properties. This enhanced sensitivity translates into potentially significant differences in projections for future water balance estimates.

Our study domain is comprised of the carbonate rock regions that cover 25% of Europe and the Mediterranean. Aquifers in these regions contribute up to half of the drinking water supply for some European countries.

We simulated the recharge volumes of our model with recharge volumes measured from independent and published karst studies over Europe and the Mediterranean. Even though there is a considerable spread across the simulations, all models show the largest recharge volumes around the Mediterranean region.

The model simulations show that the recharge volumes are strongly dependent on the degree of heterogeneity. For example, the recharge volumes in the Mediterranean region are significantly higher than in the humid regions.

EVALUATION

In the present period (1991–2010), the more realistic representation of karst processes of the heterogeneous subsurface model produces recharge rates that are 2.1 to 4.3 times larger than the recharge rates of the homogeneous representation.

Towards the end of the century (2080–2099), similar apparent fractional reductions in recharge rates of 11-12% for the heterogeneous subsurface and 14-40% for the homogeneous subsurface occur but the differences in absolute recharge rates from the present period even increase with recharge rates of the heterogeneous representation.

However, we find that our model overestimates recharge in the Mediterranean region compared to the humid regions.

GREATER SENSITIVITY

An elasticity greater than 1 or less than 0.5 indicates that annual recharge is changing stronger than the input variable, i.e., a high sensitivity. Values close to 0 indicate a low sensitivity. The two subsurface representations exhibit different sensitivities to climate variability and predict that heterogeneous regions will have a generally higher sensitivity to climate variability in the future. This is due to a more direct coupling of climatic variability and groundwater recharge variability predicted by the heterogeneous representation and shifts towards more evaporation and surface runoff for the homogeneous representation.

Our study domain covers 25% of the total land surface of Europe and the Mediterranean and it is home to ~500 Million people. Aquifers from these regions are major contributors to European water supplies and their agriculture depends 70% on irrigation. The high-present day recharge rates we found in these regions are considerably larger than estimates that assume homogeneous subsurface properties. These results explain why carbonate rock aquifers are considered highly important for Europe’s national water supplies.

Due to the more direct coupling of climate and groundwater recharge these regions will remain with high recharge rates in the future but they will require flexible water management strategies that are able to cope with variable groundwater availability across different years.

ENHANCED RECHARGE

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RELEVANCE

Overall, our results imply that subsurface heterogeneity alters water balance on a large scale. Considering it in hydrological projections is therefore relevant for present and future water management. The strong coupling of climate and recharge variability in heterogeneous regions produces more groundwater recharge than previously expected. Moreover, the increased inter-annual variability of recharge poses serious challenges for sustainable groundwater management and groundwater protection.

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SYNTHESIS

Mountain regions

Humid regions

Mediterranean regions

Desert regions

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