Development of a classification scheme for carbonate aquifers in the Mediterranean region

Key findings

- A classification scheme for karst springs has been developed to cluster carbonate aquifers according to hydraulic characteristics of the vadose and phreatic zones.
- The classification scheme can be employed to assess storage and flow characteristics of karst aquifers based on geometry and spring discharge patterns.
- The approach provides an efficient generalization tool for the management of karst aquifers in Mediterranean climates.

Motivation

Spring hydrographs contain integral information about the hydrogeological characteristics (e.g., maturity of karst, storage) of an aquifer and are largely influenced by temporal and spatial precipitation patterns. The surface topography and characteristics, as well as the geometry and hydraulic properties of vadose and phreatic zone compartments transform the original input signal according to their individual flow characteristics (e.g., storage and transmissivity). Flow processes in the individual compartments contribute to the superimposed bulk hydrograph signal at the spring (Jeannin & Sauter, 1998; Smart & Hobbs, 1986) and reveal certain aquifer properties. However, the superposition of the effects of the individual compartments makes it highly challenging to derive functional relationships. Here, we develop a method to characterize carbonate aquifers in Mediterranean climates based on their discharge signal and easily accessible aquifer characteristics. Our approach provides a valuable tool for the evaluation of aquifers in terms of their potential to provide freshwater, even under climate change conditions.

Methodology

By overlaying Mediterranean climate zones after Köppen-Geiger with a global database of carbonate rock aquifers (WOKAM), we identified 79 associated spring discharge time series from the World Karst Spring hydrograph (WoKaS) database

Spring hydrograph recession coefficient

The spring hydrograph recession coefficient is computed from the slope of the hydrograph recession curve and is composed of three typical stages (conduit, intermediate, baseflow). It is a characteristic parameter of an aquifer, which is a result of its phreatic hydrodynamic properties (Rorabaugh, 1964), such as hydraulic conductivity, storage coefficient, and aquifer geometry.

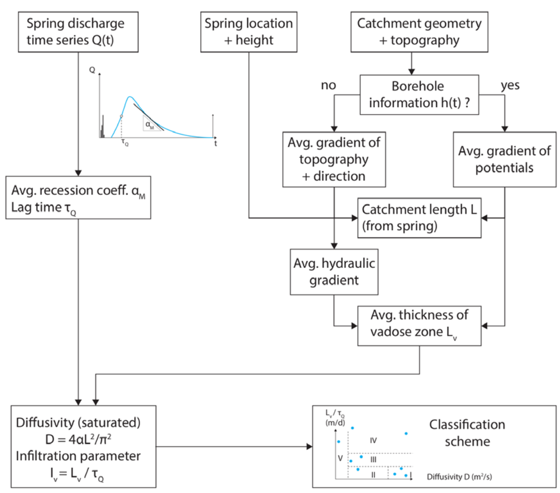

Figure 1: Workflow for the classification of carbonate aquifers located in Mediterranean climate zones

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for 65 Mediterranean carbonate rock aquifers. Rorabaugh (1964) has shown that the hydraulic diffusivity of an aquifer system can be characterized based on a spring recession curve:

$$D = \frac{T}{S} = \frac{4\alpha L^2}{\pi^2}$$

where α is the recession coefficient determined by regression analysis, and L is the average catchment length. Here, we apply this relation to provide insights into karst maturity. The infiltration parameter (I_v) can be defined as

$$I_v = \frac{L_v}{\tau_q}$$

where L_v is the average depth of the vadose zone and τ_q is the time lag between the peak time of the precipitation event and the first inflection of the spring discharge or water table fluctuation in a borehole. This parameter primarily characterizes the influence of the vadose zone, i.e., infiltration on the spring discharge signal and therefore the storage potential of the vadose zone. All available spring discharge time series of the natural aquifers are characterized in terms of these parameters and grouped into clusters.

Results

We extracted 11 hydrographs suitable for recession analysis from the dataset of 79 Mediterranean karst springs. The remaining spring hydrographs were not suitable for further analysis due to the coarse temporal resolution of the discharge time series or lack of spatial information. To evaluate the parameter space not represented by the data of existing natural karst aquifers, we applied a 2-dimensional numerical surrogate model to investigate the full spectrum of the parameter space. For each natural spring, we constructed a dual-continuum surrogate model based on average geometric properties (i.e., average length to the groundwater divide, median vadose zone thickness) and calibrated the hydraulic properties to fit the observed spring recessions. Subsequently, we altered the vadose zone thickness and the hydraulic conductivity of the conduit continuum to derive functional relationships between aquifer properties and the recession behavior. In Figure 2, the dashed vertical lines illustrate the two distinct linear scaling regimes of the vadose zone thickness and the infiltration parameter. The color represents the hydraulic conductivity of the conduit continuum. The synthetic data demonstrates the applicability of the derived parameters (i.e., unambiguity of the parameters), the infiltration parameter I_v and diffusivity D, controlled respectively by the vadose zone thickness and the hydraulic conductivity of the conduit continuum.

Application

The presented classification allows to assess carbonate aquifers in terms of their vulnerability and adequacy for groundwater abstraction without a priori detailed knowledge about the subsurface characteristics of an aquifer. Carbonate aquifers with a higher infiltration parameter and lower diffusivity are more resilient to droughts. However, high infiltration parameters may indicate a high risk of contamination. Therefore, from a groundwater management perspective the most suitable carbonate aquifers exhibit medium to high infiltration parameters and low diffusivity values. The classification may be further improved by installing automatic measuring devices in currently not monitored spring types and by including carbonate aquifers adjacent to the current Mediterranean climate zone, since it is projected to shift with climate change.

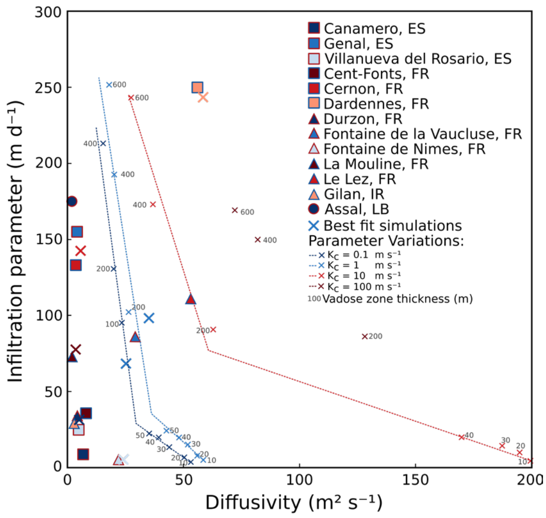

Figure 2: Classification of spring discharge time series in terms of diffusivity and infiltration characteristics. The simulated data is outlined via a cross marker, where the color indicates the hydraulic parameter of the conduit continuum and the label indicates the respective vadose zone thickness.

References

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