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, as well as the 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 superimposing effect 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 other 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 a Köppen-Geiger climate classification with a global database of carbonate rock aquifers (WOKAM), we identified 79 carbonate rock aquifers located in semi-arid Mediterranean climate zones with information about spring locations. We obtained as-

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.

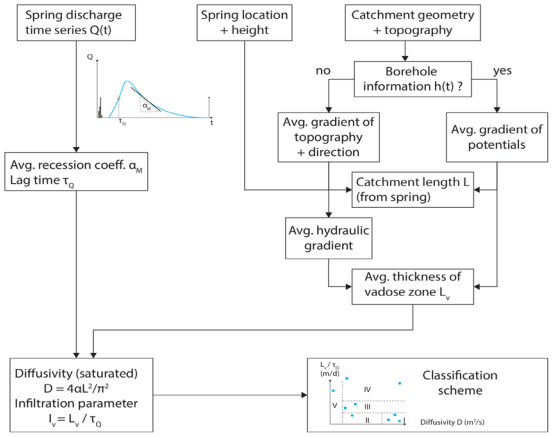

Figure 1: Workflow for the classification of carbonate aquifers located in Mediterranean climate zones

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Transfer of findings to other carbonate aquifers in the Mediterranean region

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sociated spring discharge time series for 65 aquifers from the World Karst Spring hydrograph (WoKaS) database. Rorabaugh (1964) has shown that diffusivity of an aquifer system can be characterized based on the 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 peek time of the precipitation event and the first inflection of the spring discharge. This parameter 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 time-series of the natural aquifers are characterized in terms of these parameters and grouped into clusters.

Results

Of the 79 springs located in Mediterranean climate zones, 11 hydrographs were suited to extract the relevant hydrograph parameters. The other spring hydrographs are not suitable for further analysis due to the coarse temporal resolution of the spring time-series or lack of spatial information. The 11 selected springs are characterized based on the developed classification scheme (Figure 1). The following clusters are identified: (A) Poorly karstified phreatic system with moderate-high infiltration, (B) Poorly karstified phreatic system with diffuse/slow infiltration, (C) Moderately-strongly karstified phreatic system with high Infiltration, (D) Moderately-strongly karstified phreatic system with hampered infiltration dynamics, and (E) Moderately karstified phreatic system with negligible impact of the vadose zone. Due to the few, widely distributed data points, a complete clustering of the characterized springs is not possible (Figure 2). To evaluate the parameter space that is not represented by the data of existing natural karst aquifers, as a next step we apply a simplified numerical model to investigate the full spectrum of the parameter space.

Application

The presented classification allows to determine the discharge behavior of karst springs without a-priori detailed knowledge about the subsurface characteristics of an aquifer. If the storage potential of an aquifer is known, the spring response to heavy rainfall events or droughts could be estimated. This is of particular interest facing climate change and the possibility of limited future freshwater supply and may contribute to the development of sustainable water management measures. The classification may be further refined by installing automatic measuring devices in currently not represented spring types, automatically measuring discharge at a high temporal resolution. Including carbonate aquifers adjacent to the current Mediterranean climate zone is another potential extension of the current study, since the Mediterranean climate zone is expected to expand in the future.

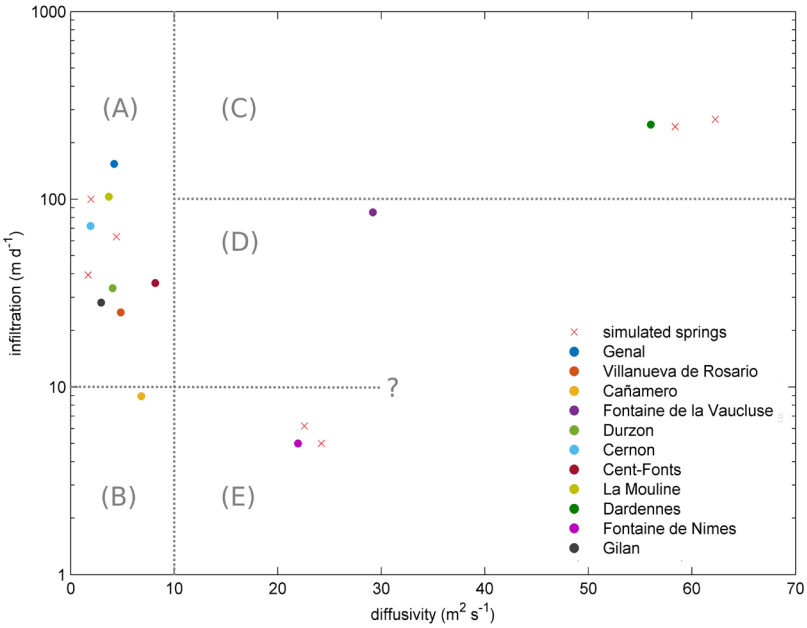

Figure 2: Classification of spring time-series in terms of diffusivity and infiltration characteristics

References

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