A Karst Conduit Probability Map for the Western Mountain Aquifer using a stochastic modeling approach

Key findings

- The stochastic approach of the Stochastic Karst Simulator (SKS) lets users investigate the uncertainty of karst conduit networks by producing a Karst Probability Map.
- Simulations based on a karst aquifer genesis model show that the geometry of karst networks is highly controlled not only by the position of present karst springs, but also by spring locations during past geological ages.
- Soft information on karst development allow for the generation of a sound hydraulic parameter field, which can be implemented in hydrological models.

Motivation

Most of the groundwater flow in carbonate rock occurs in conduits. Due to the complex structure of these conduit networks, the prediction of groundwater flow in carbonate aquifers is challenging. Yet, covering extended areas of Earth's continental surface, they host major groundwater resources and call for sustainable aquifer management strategies. Hence, understanding the governing hydrological processes is of vital importance. The Stochastic Karst Simulator (SKS) is a stochastic model to generate karst conduit networks. This study generates multiple runs of the SKS to create a Karst Probability Map for the Western Mountain Aquifer (WMA), a highly karstified and exploited carbonate aquifer in Israel and the West Bank. The method is numerically efficient, and its inputs can be easily adjusted. This makes the SKS algorithm a useful tool to rapidly test and adapt different hypotheses of karst aquifer genesis. The resulting Karst Probability Map can be input to hydrological models, which require a sound representation of the governing processes in karst systems.

Methodology

Application of the SKS algorithm requires the development of a conceptual model of the aquifer's karst genesis. Soft information from this conceptual model, such as karstifiable formations or identified present or past inlet (dolines or swallow holes) and outlet (springs) locations, are used as input to the SKS. The method itself is based on four main steps, as summarized in the Box. Multiple runs of the SKS are applied to create a 2D Karst Probability Map. In each run, the location of inlets for the WMA is determined randomly along a calculated flow accumulation from a digital elevation model (DEM) of the aquifer's recharge zone. No field information about individual inlets are known. Outlet locations are equally randomly generated within given bounds based on the karst genesis model.

Results

Figure 1 presents the conceptual model of karst genesis in the WMA. Three different phases of karstification are identified. During phase 1, a paleo-discharge zone exists, located close to the present-day coastline of Israel. In phase 2, which represents a period of extremely low sea levels during the

Stochastic Karst Simulator (SKS)

The "Stochastic Karst Simulator" (SKS) developed by Borghi et al. (2012) is a stochastic model to generate 3D karst conduit networks. The method is based on the following steps: (1) building a hydrogeological model, (2) adding structural heterogeneities (faults and fractures), (3) identifying present and past inlet and outlet locations, and (4) generating the conduit network by computing a minimum-effort path between inlets and outlets.

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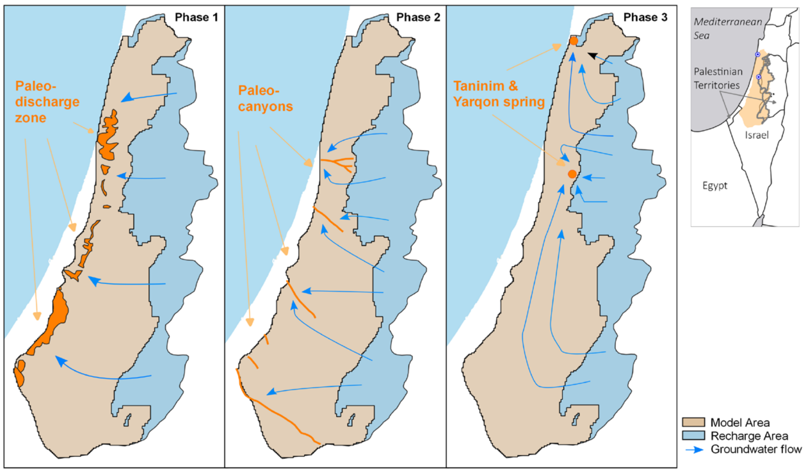

Figure 1: Conceptual model of karst development in the WMA. Phases of karstification: 1 - Paleo-discharge zone, 2 - Paleo-canyons, and 3 - Modern-day conditions.

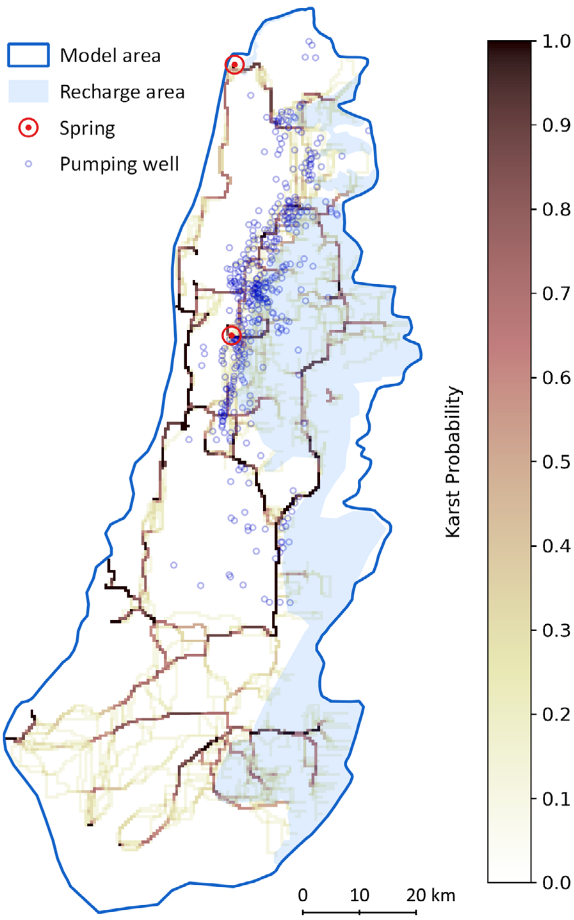

Figure 2: Karst Probability Map of the WMA, showing the spatial distribution and probability of karst conduits in the model area

Messinian Age (around 5 Ma BP), paleo-canyons formed along this coastline, providing discharge points for the WMA. Phase 3 shows the modern-day outlets of the aquifer, the Yarkon and Taninim springs. The resulting Karst Probability Map for the WMA, composed of multiple runs of the SKS, is presented in Figure 2. The location of the most productive pumping wells in the region are also shown, assuming high yield due to high karstification in these areas. Two apparent trends in the orientation of the network itself are identified: 1) conduits extending east to west, from the recharge area to the present-day coastline of Israel, and 2) conduits extending south to north towards the present-day spring locations. Many of the S-N trending conduits branch off from pre-existing E-W trending conduits. The iterative approach of the SKS algorithm allows to account for these trends in agreement with the 3-phase karst development in the WMA.

Application

The SKS algorithm is a useful tool to test different hypotheses of karst genesis and to understand the evolution of karst network geometries. Otherwise unavailable spatial information about the geometry and distribution of karst conduit networks, especially in areas the size of the WMA model area (ca. 6000 km²), is made accessible with the presented simulations. The stochastic approach also enables users to investigate the uncertainty of generated networks in the form of Karst Probability Maps. Tools like the SKS can help to better understand karst aquifers by implementing the resulting network in a hydrological model, which predicts an aquifer's response to changing conditions (e.g., altered precipitation patterns).

References

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