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The Elaborated Ancient Water Supply System of Resafa. Risk and Uncertainty of Water Harvesting in the Syrian Desert Steppe

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Hydrological modeling; geoarchaeology; HEC-HMS; CAESAR-lisflood; palaeorainfall; SPI.

Introduction

Resafa (Rusafa, Ar-Rasafeh, Sergiopolis), initially a fortified Roman military post in the Syrian steppe, has been a Christian pilgrimage site and was the residence of the Ummayyad Caliph Hisham ibn ʻabd al-Malik. Nowadays, the well-preserved city walls, ruined churches and large cisterns attest to Resafas former religious, political and economic importance that lasted from the 1st to the 13th century AD. The city is located ∼ 25km to the south of the Euphrates at the confluence of various wadi systems that drain the surrounding undulating desert steppe (Fig. 1a). Because perennial water sources are absent and the groundwater is brackish here, the drinking water supply of the city had to rely on the collection and storage of water from rainfall and runoff events. This was conducted by applying two water-harvesting techniques: (I) rooftop harvesting and storage in bottle-shaped cisterns, and (II) floodwater harvesting and storage in large subsurface cisterns. From previous excavations it is known that the floodwater-harvesting system consisted of a ∼ 450m long earthen dam that blocked parts of the wide alluvial plain to the west of the city wall (Fig. 1b). In the case of a runoff event, the dam retained the floodwater and, in consequence, a temporal water reservoir built up. Connected to this reservoir was a channel that conveyed the water via an opening in the city wall into the cisterns (Fig. 1b). Besides these excavated structures, aerial photos from the beginning of the 20th century suggest that additional structures such as dikes and retaining walls along the wadi course were built to control the floods. Nevertheless, alluviation, modern road constructions and earthworks for irrigation and farming hamper a ground truthing of the aerial photos, and recent excavations could only reveal parts of the assumed structures. Moreover, little is known about the climatic and hydrological conditions that prevailed in this region. At present, estimates of the amounts of water which could potentially have been harvested are rather vague.[1] Resafa is situated in a region where the rainfall regime is characterized by strong inter-annual and decadal fluctuations in annual rainfall amounts, and droughts are a common feature. As the drinking water supply of Resafa relied largely on rain, the city was directly affected by these fluctuations.

Thus the major aims of this study are to:

- Estimate climate variability in the region during the past 2000 years based on literature and climate modeling.
- Characterize the rainfall regime with the emphasis on inter-annual variability and the magnitude-frequency of rainfall events.

The analysis and results of the climate model was done and provided by Janina Körper (FU Berlin).

1 Brinker 1991; Berking, Beckers, and Schütt 2010.

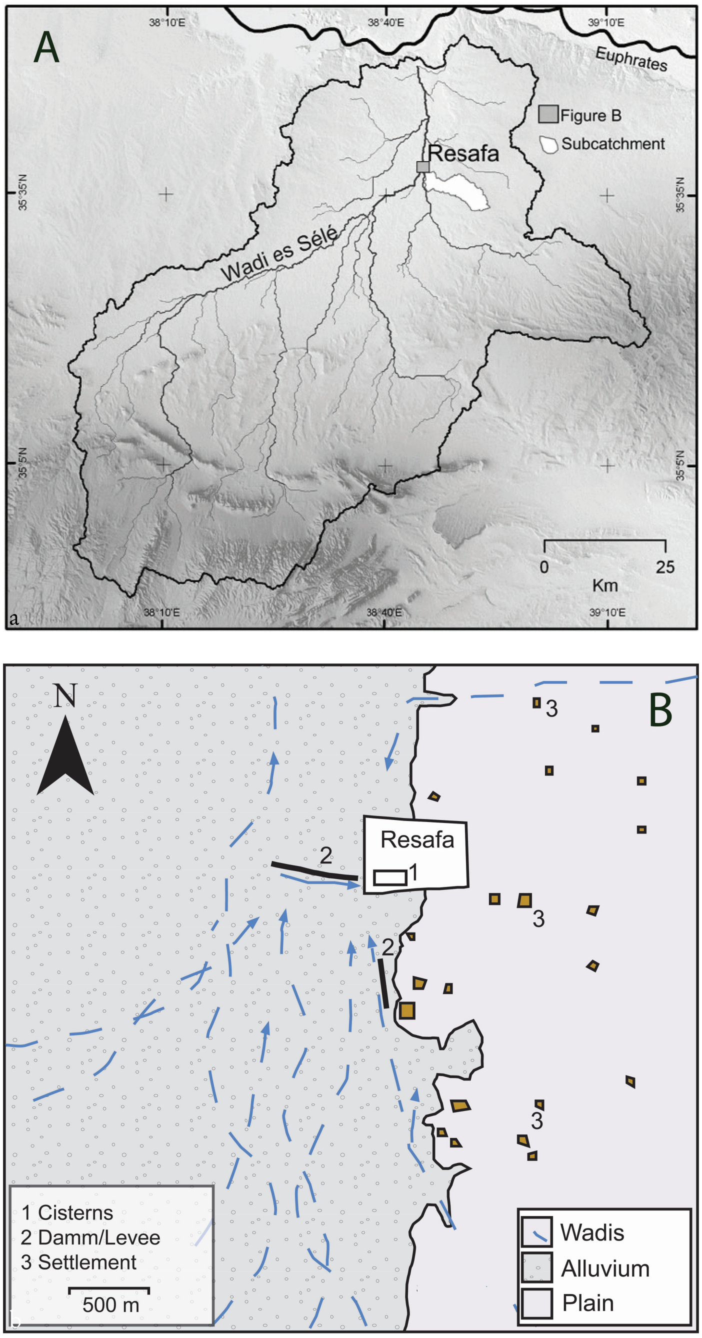

Fig. 1 | (a)Catchment of the Resafa Basin. The rainfall-runoff model was run for the subcatchment, (b) Catchment of the Resafa Basin. The rainfall-runoff model was run for the subcatchment. 1 B: Sketch of the hydrology and hydraulic structures in the vicinity of Resafa.

- Evaluate the rainfall-runoff characteristics of the region applying a rainfall-runoff model
- Evaluate the effect of hypothetical hydraulic structures applying a parsimonious 2D hydraulic model.

Methods

To estimate whether the climate changed in the region during the past 2000 years, we applied the climate model ECHAM5[2] with a resolution of 1°×1°. It was run for selected time slices (2000 BP, 1000 BP, pre-industrial and present climate).

2 Roeckner et al. 2003.

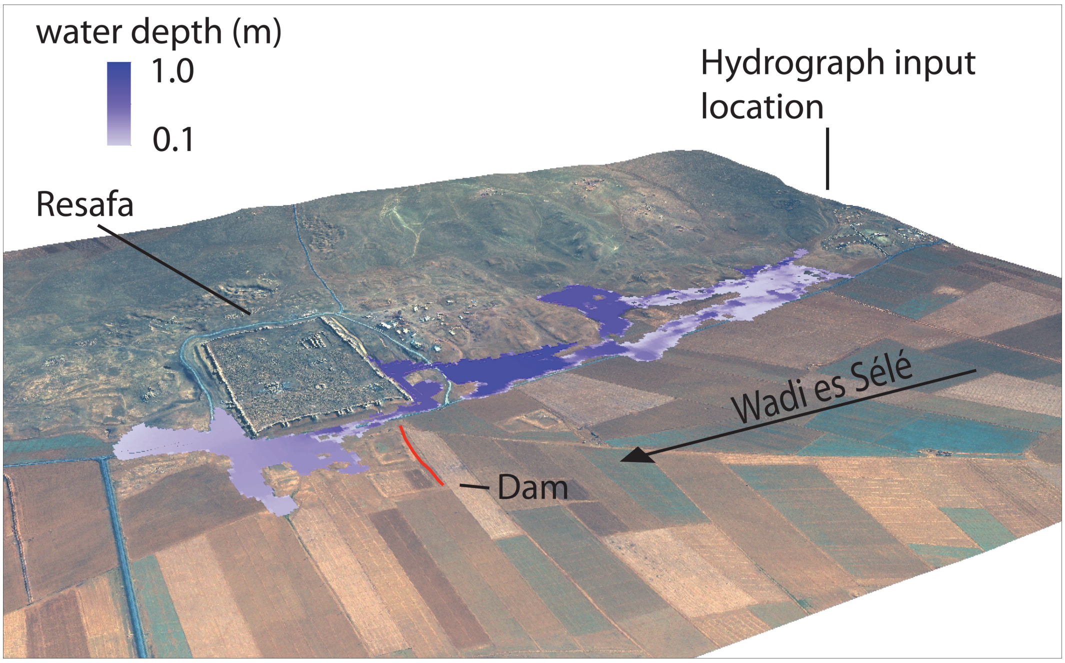

Fig. 2 | 3D sketch of the 2D hydraulic modeling result. The hydrograph input location is the outlet of the sub-catchment in Fig. 1a–1b.

The characterization of the rainfall regime is based on the Famine Early Warning System ARC2 dataset with a temporal resolution of one day and a spatial resolution of 0.1°×0.1°, covering the period 1983 to present. The dataset is generated using a combination of satellite rainfall estimates and gauge measurements.

To estimate hydrographs and the rainfall runoff character of the region, the rainfall runoff model HEC-HMS was applied. The physical characteristics of the catchment were parameterized by curve numbers and HEC-GeoHMS. The daily rainfall amounts were converted to hypothetical storms using the SCS synthetic rainfall distribution type II which is typical for drylands.[3] To validate the computed hydrographs, generated peak discharge values were used as an input into a 1D hydraulic model (HEC-RAS) and tested against peak stage estimates obtained from cross-channel measurements in the major contributing wadi.

The obtained hydrographs were used as an input in a 2D hydraulic model (Lisflood implemented in the CAESAR-Lisflood software). The major purpose of the application of the model in this study was to route the floods along the alluvial plain in the vicinity of Resafa. The model was run under two scenarios: (I) the current topographic situation represented by a high resolution digital elevation model (DEM) with a vertical resolution of one meter and a horizontal of 5m, and (II) with a DEM that includes proposed hydraulic structures which were based on the photographs from the early 20th century and findings from recent excavations.

Preliminary Results and Conclusion

The climate model confirms previous proxy-based and climate-modeling results, which showed that the climate over the past 2000 years in the Eastern Mediterranean was in general similar to today's. The present day rainfall data can therefore be assumed to be

3 Awadallah and Younan 2012.

representative for the rainfall regime of Resafa during its heydays. The analysis of the rainfall data is ongoing and will be presented in a forthcoming publication.

The rainfall-runoff model obtained reasonable results. The runoff coefficient varied between 0.04 and 0.2; values which are typical for semi-arid catchments.[4] Moreover, the water level calculated with HEC-RAS and the hydrographs of the rainfall-runoff model met with peak stage estimates measured in the field.

The 2D hydraulic model shows that, under current conditions, the floods flow past the dam along the moat that surrounds the city (Fig. 2). It is therefore likely that additional hydraulic structures existed. These are currently implemented in the DEM and will be presented with the results from the rainfall analysis.

The preliminary results are promising and show that our approach is suitable for gaining further insight into the water supply system of Resafa.

4 Lesschen, Schoorl, and Cammeraat 2009.

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