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Editorial

Groundwater Modelling in Karst Areas

Andrea Zanini [1], Alessandra Feo [2], Emma Petrella [2] and Fulvio Celico [2,*]

[1] Department of Engineering and Architecture, Parma University, Parco Area delle Scienze, 181/A, 43124 Parma, Italy; andrea.zanini@unipr.it
[2] Department of Chemistry, Life Sciences and Environmental Sustainability, Parma University, Parco Area delle Scienze, 157/A, 43124 Parma, Italy, alessandra.feo@unipr.it (A.F.); emma.petrella@unipr.it (E.P.)
* Correspondence: fulvio.celico@unipr.it

This Special Issue focuses on recent advances and future developments in the modeling (both conceptual and numerical) of flow and transport in karst aquifers. This includes mainly numerical simulations of saturated/unsaturated flow, seawater intrusion, recharge processes and statistical approaches. Six papers have been selected that cover a wide range of problems including (i) evapotranspiration estimates based on satellite data, (ii) both explicit conduits and the unsaturated zone in karst reservoir hybrid models, (iii) matrix-conduit exchange modeling in both the epikarst and the transmission zone, (iv) stable isotope analysis and tracing tests to characterize regional hydrogeological features, (v) the mapping of groundwater spring potential using novel ensemble bivariate and multivariate models and (vi) numerical simulations of the saltwater wedge in coastal aquifers with a double conduit network. The main findings of this research are summarized in this editorial.

Hernandez Diaz et al. [1] investigated a coastal karst aquifer in Cuba. Experimental data suggested the presence of a double conduit network that connected the saline water to the inland. In order to understand the whole saline intrusion process, Feo et al. [2] developed a simplified numerical model of the investigated aquifer in which the conduit network was modeled as a high hydraulic conductivity layer. Sensitivity analyses were applied to evaluate the impact of the parameters (hydraulic conductivity, vertical anisotropy and salinity concentration) and boundary conditions on the modeling saltwater wedge. The authors compared the numerical results obtained considering different scenarios with field data (electric conductivity profiles measured in a well), confirming the conceptual model proposed by Hernandez Diaz et al. [1] and the karst nature of the investigated aquifer.

Nhu et al. [3] developed an approach to map the distribution and discharge potential of a karst spring on the basis of various hydrogeological factors and applied the method to a case study in Iran. Spatial mapping was achieved using ensemble modelling, which was based on certainty factors (CF) and logistic regression (LR). Maps of the CF and the LR components of groundwater potential were generated individually and then combined to prepare an ensemble map of the study area. The analysis showed that the LR outperformed the CF in terms of the comparison between model predictions and known occurrences of karst springs (i.e., calibration data). The combination of the CF and the LR results through ensemble modelling produced superior accuracy in terms of spring potential mapping avoiding the weaknesses of the CF and the LR methods.

Dogančić et al. [4] presented several investigation actions performed to better characterize the hydrogeological characteristics of Kazeroo County (Iran). The new knowledge is of significant importance for managing the karst aquifer for water supply purposes. The authors performed a stable isotope analysis (D and ^{18}O) and tracer tests. These analyses showed that groundwater resources northwest of the Kazeroon County have great potential for the water supply of the city. The transit times of the tracers showed that the underground system had a fast response to precipitation. The results of the water stable isotope measurements showed that the catchment area of the karst springs near Kazeroon

Citation: Zanini, A.; Feo, A.; Petrella, E.; Celico, F. Groundwater Modelling in Karst Areas. *Water* **2021**, *13*, 854. https://doi.org/10.3390/w13060854

Received: 18 March 2021
Accepted: 19 March 2021
Published: 20 March 2021

was probably over 2000 m in the area of the Shahneshin anticline and was lower than the catchment area of the Arjan spring.

Dal Soglio et al. [5] evaluated the capability of hybrid models of karst aquifer that couple a single continuum medium with discrete features to properly reproduce interactions between a vertical conduit and the surrounding unsaturated matrix. The authors showed the ability of hybrid models to reproduce the most significant behaviors described in the literature such as transient storage and distribution of recharge, flow concentration towards conduits in the epikarst and matrix-conduit exchanges varying in time and space. The study also highlighted the need to deepen the knowledge of the scaled medium properties we need to know to apply such models to actual cases.

Dal Soglio et al. [6] focused interest on hybrid models that take into account both unsaturated subsystems and discrete conduits to simulate the reservoir-scale response, especially the outlet hydrograph. The authors developed a synthetic karst aquifer model to test the approach. They performed simulations for several parameter sets and showed the ability of hybrid models to simulate the overall response of complex karst aquifers. Varying parameters affected the pathway distribution and transit times, which resulted in a large variety of hydrograph shapes. The relationships between the model parameters and the hydrograph characteristics were not all linear: a few of them had local extrema (e.g., peak flow time vs. thickness of the epikarst) or threshold limits (e.g., all characteristics vs. the thickness of the transmission zone). The numerous simulations helped to assess the sensitivity of the hydrograph characteristics to the different parameters and, conversely, to identify the key parameters that could be manipulated to enhance the modelling of field cases. The hybrid models were able to reproduce the flow processes at the interface between the matrix and the conduit and also to simulate the overall response of complex karst aquifers.

Ruggeri et al. [7] highlighted the importance of a karst aquifer for water supply. The quantification of the recharge and its dependence to hydrological parameters is crucial in this aim. The integration of terrestrial and remotely sensed data is a promising approach to limit uncertainties due to spatial and temporal inhomogeneity of networks of meteorological stations as well as variable geomorphological features and land use across mountainous karst areas. The authors estimated the actual evapotranspiration and groundwater recharge for karst aquifers of the southern Apennines using remotely sensed data gathered by the Moderate Resolution Imaging Spectrometer (MODIS) satellite in the period 2000–2014. The authors compared the obtained results of the proposed approach with classical ones used for the estimation of evapotranspiration. The application of the MODIS satellite data was demonstrated to be a practical tool to estimate the actual evapotranspiration and reduce the uncertainty due to the spatial and temporal inhomogeneity of meteorological networks. The authors showed a good agreement between the actual evapotranspiration estimated through the proposed approach and the potential one computed through a Thornthwaite formula. The results achieved allowed advances in the assessment of the groundwater recharge of the karst aquifers at a regional scale to be obtained.

On the whole, the papers published within this Special Issue point out the existence of a wide range of topics related to karst hydrogeology; for example, (i) a recharge estimation, (ii) unsaturated/saturated flow, (iii) flow in karst conduits in the fracture network at the interface between the matrix and conduits and (iv) seawater intrusion that can be refined exploring several types of experimental/statistical/numerical approaches. In a wider and methodological perspective, the same papers further demonstrate the added value of mixing different approaches such as (i) experimental and statistical [8], abiotic and biotic [9], carried out at field and lab-scale [10] and also highlighted the importance of the knowledge of hydraulic parameters [5,11,12].

To conclude, we hope that this paper collection can contribute to opening new frontiers within the hydrogeological community and stimulate interdisciplinary and hybrid research.

Acknowledgments: As guest editors of this Special Issue, the authors acknowledge the journal editors and all authors submitting manuscripts to this Special Issue. Special thanks are extended to

the referees who diligently reviewed all of the submissions, which greatly improved the quality of the published papers.

Conflicts of Interest: The authors declare no conflict of interest.

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