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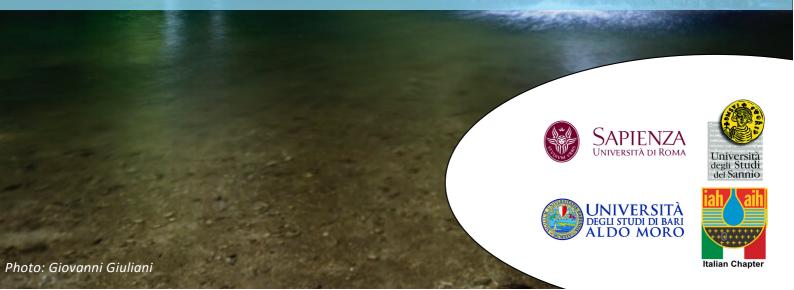
Eurokarst 2024 Abstract book

Editors

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Italian Chapter

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TOPIC 1
Methods and models in karst hydrogeology
ORAL PRESENTATIONS

A Bayesian Multi-Model Framework for lumped parameter model structure selection and parameter estimation in karst hydrology.

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Abstract

Lumped parameter modelling in karst hydrology has been widely developed in the last decades. Model conceptualization often leads to one unique model structure and skips the assessment of potential model structure equifinality. Some studies consider various model structures to account for this source of uncertainties in hydrological predictions but still do not assess the equifinality between various model structures. This issue is particularly important for karst hydrology, where hydrological systems are highly heterogeneous and information about the structure is difficult to obtain. In this work, we developed a Bayesian Multi-Model Framework (BMMF) allowing us to estimate a model structure probability distribution associated with their model parameters. Such an approach constitutes a significant step forward compared with classical calibration allowing (i) to provide a robust hydrological predictor considering both structural and parametric uncertainties, and (ii) to avoid epistemic error due to model structure selection, which is generally influenced by the subjective conceptualization of the karst hydrological system by the modeler. The methodology is illustrated with a Bayesian inference procedure among a large set of lumped parameter model structures considered for the simulation of discharge at Fontaine de Vaucluse karst spring (southern France).

Keywords: Lumped parameter modeling, Bayesian, Uncertainties

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A rainfall-input model based on Artificial Neural Network (ANN) and cross-correlation analyses for karst spring discharge simulation.

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Abstract

Due to climate change and increasingly frequent drought events occurring in the Mediterranean area, sustainable management of groundwater resources based on reliable simulations and previsions of karst spring discharges is required. In many cases, the limited information on spring discharge patterns is a big issue for spring discharge forecasting, as well as the understanding of karst hydrological processes. In order to plan sustainable water resource exploitation, the groundwater availability needs to be assessed by monitoring the spring discharge along the hydrological year. When continuous spring flow measurements cannot be carried out at the required time scale or there is a lack of data in long-time discharge series, spring discharge estimation is necessary. Several research studies proposed methods based on relationships between spring discharges and rainfall data as input. The aim of this paper is to discuss the factors that control karst spring discharge patterns, according to rainfall inputs at different time scales. A model based on Artificial Neural Network (ANN) data training and cross-correlation analyses has been developed to estimate the discharge of some karst springs in Umbria Region (Central Italy). Modelled discharges have been compared with measured ones, obtaining good results in terms of RMSE. The duration of the period considered for input data is quite important for the results, being the lag time from input to output strictly related to the aquifer storage properties, and can be estimated by cross-correlation analysis.

Keywords: karst spring, groundwater, discharge modelling, water management

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Analysis and modeling of the complex recharge-discharge relationship of the Caposele karst spring (southern Apennine)

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Abstract

Karst aquifers represent a major source of groundwater and provides drinking water to population in many regions of the World. Although several factors control the recharge-discharge processes within karst aquifers, precipitation and temperature are the primary drivers for groundwater storage and spring discharge variability. In particular, recharge-discharge processes occur and evolve over different time scales and strongly depends on the climate regime and its variability. Understanding the response of karst aquifers to the hydrological input is of great relevance for a better assessment of groundwater resource variability in response to climatic or anthropogenic factors and requires specific numerical modelling approaches. Due to the complexity of karst hydro-systems and the lack of distributed information, physically based modelling of karst aquifers may result challenging. For these reasons, and also because the only available data often consist in discharge time series at spring, lumped parameter models are usually considered of rainfall discharge modelling. The Cervialto karst system was investigated because of the absence of any anthropogenic disturbance and its peculiar hydrological and hydraulic behavior in response to the meteorological input. Unlike typical karst aquifers, this karst system shows a strongly smoothed and delayed response to the meteorological input. The KarstMod modelling platform was applied to simulate discharge of the Caposele karst spring (Cervialto massif, southern Italy) on a daily scale and to better characterize recharge-discharge processes within this complex karst system. Due to the articulated topography and spatial climate variability of the spring catchment, specific approaches were applied to estimate the meteorological signal depending on rainfall, snowfall, snow accumulation/melting, and evapotranspiration. Successively, several model structures were tested, and model parameters were calibrated based on the daily discharge time series of the Caposele spring. The calibrated model provided good performance and successfully simulated the smooth behavior of the Caposele spring on a daily scale, characterized by the complete absence of discharge peaks following intense rainstorms. In addition, the model replicates the long memory effect of the aquifer and the flat hydrograph shape observed in drought years. Nevertheless, the analysis highlighted a general difficulty in calibrating models able to replicate both discharge peak amplitude and timing, which is

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probably due to the peculiar hydrological and hydraulic behavior of the Cervialto massif. Indeed, the surface features of the massif, characterized by a pyroclastic soil covering the karst slopes and filling karst depressions, and the absence of a well-developed and interconnected conduit network, probably delays the infiltration within the karst aquifers and thus partly explains the smoothed and dampened observed hydrological response the Caposele spring, rarely observed in regions of karst terrains. The calibrated model provides a powerful tool that might be consider in the future to investigate in detail the response of the Caposele spring to climate variability and change.

Keywords: karst spring, recharge, discharge modeling, lumped parameter model

Application of time series analysis in complex karst aquifers: a case study of the Javorniki karst aquifer (SW Slovenia)

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Abstract

Karst aquifers have a very heterogeneous structure and complex hydrodynamics through conduits, fractures and the matrix, therefore the characteristics of groundwater flow and solute transport differ from those in intergranular and fissured aquifers. To understand how they work, appropriately adapted hydrogeological research techniques and analyses are required.

The advanced application of time series analysis was performed for the Javorniki karst aquifer, which is known for its complex hydrodynamics and mixing of water from different sources of recharge. The aquifer covers an area of almost 800 km2 and is recharged by both an allogenic and an autogenic component, which can vary depending on the hydrological conditions. The water is then discharged out of two main springs, one of which is an important source of drinking water.

A monitoring network was set up around the aquifer. A classical approach with high temporal data resolution was extended to a spatial domain with simultaneous monitoring of precipitation and water flow in springs, ponors and water-active caves. The main objectives were to define and compare the flow characteristics and storage capacity of selected springs and to determine the influence of different types of recharge (autogenic versus allogenic). The time series of recharge were analysed as input functions in the correlation and spectral analysis. The results undoubtedly show differences in the water transfer through the system, in the storage capacity and in the recharge characteristics. However, they also show the limitations of using cross-correlation functions to differentiate between the influence of autogenic and allogenic recharge. Due to their mutual influence, the interpretation of results in complex karst systems can be ambiguous. To investigate the separate influence of allogenic and autogenic recharge on springs, a partial cross-correlation analysis was also introduced. The results confirmed that this approach provides additional insights into the functioning of binary karst aquifers.

Keywords: karst aquifer, autogenic and allogenic recharge, time series analysis, partial cross correlation, Slovenia

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Assessment of groundwater-river interactions in the carbonate formations of the northeastern Aquitaine Basin (France)

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Abstract

Interactions between groundwater and rivers play a key role in the functioning of hydrosystems. Identifying and quantifying these exchanges is therefore crucial to ensure water resources management (low-water support, flood events, etc.), as well as maintaining biodiversity.

In the north-east of the Aquitaine Basin (South-West of France), the carbonate aquifers of the Jurassic and Cretaceous periods constitute strategic reservoirs that meet the majority of the region's water needs (drinking water, irrigation, industry, etc.). These aquifers, which are also affected by karstification, are closely linked to surface environments, including rivers, and thus help to maintain the associated ecosystems and activities, particularly during periods of low water. In addition, these aquifers, located in edge zones of the sedimentary basin, benefit from surface runoff from the bedrock at the head of the basin, which recharges the karsts, as well as from formations further downstream or at depth. Analysis of groundwater-river exchanges is therefore essential in this region.

The Eaux-SCARS regional project (https://sigesaqi.brgm.fr/-Projet-Eaux-SCARS-.html), aiming to understand the hydrogeological functioning of the CArbonate aquifers of the north Aquitain Basin, integrates several actions to assess the nature of exchanges. Investigations focused mainly on 5 rivers structuring the territory, with average interannual flows ranging from 7 m3/s for the smallest systems to 190 m3/s for the largest.

The first action is a series of field campaigns involving piezometric measurements (2 campaigns, each involving more than 200 borehole measurements and 56 stream levelling) and sampling of rivers and groundwater (6 campaigns involving nearly 1,800 analyses of major ions, dissolved elements and isotopes), aimed to better understand how groundwater is recharged by rivers losses at regional scale. The second action consists of continuous flow, temperature and conductivity monitoring along certain stretches of the hydrographic network (14 stations along 4 rivers), in order to identify infiltrating or draining sections according to hydrological conditions. Serial gauging campaigns complete this monitoring. In this way, changes in low-water flows on more than 80 stretches were assessed. A last action was to test the relevance of the thermal approach to highlight groundwater contributions to river flow. The principle of the thermal approach is based on the temperature contrast that can

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exist between surface water, corresponding to river water, and groundwater. This approach, tested in winter over 4 km long, made it possible to clearly identify groundwater discharges into the river and groundwater remaining in the form of concentrated inputs.

These various actions, some of which are still underway, will lead, among other things, to the production of piezometric maps, the evolution of flows by section and the estimation of the contribution of groundwater or rainwater to river flow. These combined results make it possible to evaluate the modalities of groundwater-river interactions by sector. It helps as well to better define the areas at stake in terms of groundwater recharge or surface water support, for quantitative management, in line with the region's water needs, particularly for drinking water and irrigation.

Keywords: groundwater, river interactions

Changes in snow dynamics as a proxy for groundwater recharge in Euro-Mediterranean karst mountains

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Abstract

Mountain regions are the water towers of the world and supply substantial water use and ecosystems in the subjacent lowlands. As a significant amount of water can be stored in mountains as snow, the hydrological regime in mountain catchments could be drastically altered by changing climate conditions. There might be long-lasting droughts due to the absence of snowmelt in spring or summer, and unexpected floods because of the sudden snowmelt events. Considering the fast recharge, drainage, and discharge dynamics of the karst aquifers, mountain karst regions would become the pioneers of these hydrological regime changes, particularly in the Euro-Mediterranean region which is one of the potential hotspots of climate change. There are very important mountainous karst aquifers in the Euro-Mediterranean region recharging by the Atlas Mountains, Pyrenees, Central Alps, Apennines, Dinarides, Carpathians, Taurids, and Zagros Mountain series, as well as by many other individual mountains. Recent studies showed that most of these mountain ranges are experiencing a decline in snow cover at various stages. In the present study, we focused on the investigation of snow cover changes and their impact on groundwater recharge in the Euro-Mediterranean karst mountains, using the daily snow cover maps obtained from MODIS satellites. Due to the decreasing precipitation and increasing air temperature, the snowline elevation is shifted to higher altitudes, and the fractional snow-covered area is decreased; furthermore, the increase in the air temperature and the decline in the snow cover boosted the evapotranspiration from soil and shallow part of karst systems. To verify the investigation results, we estimated groundwater recharge rates for the karst aquifers in the Hochschwab and Mieming Mountains of Austria by using the VarKarst-Snow model.

Keywords: Mountainous karst, Snow cover, MODIS, Climate change, Hydrological model

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Characterization and classification of karstic groundwater resources

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Abstract

Karst aquifers are often described as complex, highly heterogeneous hydrosystems. Groundwater flow is difficult to describe in the karstified geological reservoir, both spatially and temporally, but most (if not all) of the groundwater flow naturally converges on a limited number of outlets. Consequently, the hydrological and physico-chemical responses of karst springs provide a comprehensive understanding of the functioning of the karst system, which is the basis of the systemic approach.
Accordingly, numerous graphical, statistical or signal processing methods have been proposed to describe the rainfall/discharge relationship and get some indicators derived from the analysis of karst spring hydrographs. These indicators have been used to classify the hydrological functioning of karst systems whatever the climatic context since the work of Mangin (1975), but how can these classifications be modified to account for the availability of karst groundwater resources?

The XLKarst tool (Bailly-Comte et al., 2023) is used to apply these methods to a database of 3-year daily precipitation and flow time series collected during the hydrogeological study of the karst groundwater resources of the Causse Méjean by the Cevennes national Park (PnC) and the French Geological survey (BRGM report RP-70327-FR). Six distinct karsts systems draining the same karst plateau have been monitored to get their discharge evolution in response to relatively homogeneous recharge events on the karst plateau. This enables a direct comparison of the results in terms of karstic functioning, avoiding biases due to different climatic contexts. This presentation will first describe the functionalities of the XLkarst tool as applied to the Causse Méjean dataset. In addition to classical hydrological time-series analysis, a new approach for karst spring recession analysis will be presented based on the continuous baseflow separation of Duncan (2019). The results will be used (i) to discuss the strength and weakness of classifications of the hydrological functioning of karst systems based on recession curve analysis and base flow separation methods, and (ii) to propose an alternative that highlights the availability of the karst groundwater resources.

Bailly-Comte, V., Ladouche, B., Charlier, J.B., Hakoun, V., Maréchal, J.C., 2023. XLKarst, an Excel tool for time series analysis, spring recession curve analysis and classification of karst aquifers. Hydrogeology Journal 31, 2401–2415. https://doi.org/10.1007/s10040-023-02710-w

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Duncan, H.P., 2019. Baseflow separation – A practical approach. Journal of Hydrology 575, 308–313. https://doi.org/10.1016/j.jhydrol.2019.05.040

Mangin, A., 1975. Contribution à l'étude hydrodynamique des aquifères karstiques, PhD thesis, Université de Dijon, Dijon, France, 1975. https://hal.archives-ouvertes.fr/tel-01575806

Keywords: Correlation and spectral analysis, recession analysis, classification

Characterizing groundwater springs in the Italian Alps: an integrated geological, geophysical, and hydrogeological approach

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Abstract

Spring water is one of the major sources of drinking water for local communities throughout the Italian Alps and in mountain areas worldwide. As water demand and pressure on groundwater resources increase in the context of a fast-changing climate, there is a growing commitment to assess groundwater availability and develop sustainable water supply strategies.
The proper management of groundwater resources requires the characterization of the aquifer systems. In this regard, karst terrains pose unique challenges due to their complex and heterogeneous nature. This study focuses on the assessment of an aquifer system in a karst-fissured mountain environment, by employing an integrated approach based on three pillars: geology, geophysics, and hydrogeology. The study area, located in the Brescia Prealps (northern Italy), is characterized by a Lower-Middle Triassic succession with a fold-and-thrust architecture, typical of the Southern Alps domain.

The geological pillar is based on a 3D geological model developed using both bibliographic data and field observations. This model serves as the foundation for understanding the spatial distribution of geological formations and the major tectonic lineaments.

The geophysical pillar is built on both ground-based geophysics (classic electrical tomography, ERT, and innovative transient EM methods, TEM) and on densely spaced airborne electromagnetics (AEM).

The hydrogeological pillar consists of groundwater chemical analysis and stable isotope analysis of Oxygen, Hydrogen, and Carbon.

Geophysical surveys play a key role in capturing the subsurface heterogeneity and identifying preferential flow paths within the rock volumes. The integration and mutual calibration of geophysical data with the 3D geological model allows for the refinement and validation of the model parameters, ensuring a more realistic representation of the aquifer system. This iterative process of mutual calibration enhances the precision of the model and provides valuable insights into the hydrogeological characteristics of the investigated system. Hydrogeology,

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and particularly the isotope analysis, helped to identify the recharge areas of the aquifer system.

The results reveal the existence of 4 rock volumes with similar electrical behavior, within which heterogeneities in resistivity distribution are recognized. In addition, the integration of 3D geological modeling and geophysical surveys provides a comprehensive and accurate representation of subsurface structures.

In conclusion, this research offers practical insights into the sustainable management of groundwater springs in complex geological settings and is the first step in the development of a numerical flow model, which is essential for the assessment of groundwater availability as a function of climate change scenarios.

Keywords: Karst fissured aquifer, 3D geological modeling, Electrical resistivity tomography, Airborne electromagnetics

Climate Change and spatio-temporal variability of the freshwater-saltwater interface in endokarst lakes of coastal aquifers in Mallorca, Balearic Islands, Spain

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Abstract

The mixing zone between fresh and saltwater in coastal karstic aquifers is perhaps the most interesting hydrogeological zone to study the impact of Climate Change on groundwater. Historically, the interface has been understood as a relatively homogeneous and static zone, with three distinct parts: a) freshwater in the upper part, b) brackish water in the intermediate margin, and c) saltwater in the lower zone. However, this classic interface model, based on a moderate advancement or retreat of the interface according to precipitation patterns, cannot be applied to the actual evolution of the interface in the majority of coastal karstic aquifers in the Mediterranean. The study of the interface in endokarstic lakes of four groundwater aquifers on the island of Mallorca has revealed that the interface is composed only of two zones: a) a brackish water zone (with a conductivity exceeding 7500 μS/cm and 2100 mg/L of chlorides), and b) a saltwater zone below the former (53000 μS/cm and 36000 mg/L of chlorides). However, the thickness of the brackish zone varies significantly among the endokarstic lakes, with some having a brackish zone up to 10 m deep and others only 1 m deep. This hydrogeological model of the interface in all cases shows a variation towards the interior, where chloride concentration and conductivity decrease, with a very gradual geometry from the coastal area. The freshwater zone is only observed at the head of the aquifer, far from the sea (more than 2 km). The notable physicochemical differences in the interface between the coastal endokarstic lakes of Mallorca, despite their proximity, are mainly attributed to local anthropogenic causes, masking the effects of Climate Change on the advancement or retreat of the interface. There is also observed variation in the thickness of the brackish zone among aquifers, indicating both high hydrogeological compartmentalization and variable anthropogenic pressure depending on the specific location of the analyzed areas. For example, Es Coll Cave in Porto Colom, located beneath an urbanization, exhibits very high chloride concentrations (above 17500 mg/L), in contrast to Genovesa Cave, very close but with 2100 mg/L. However, Es Dolç Cave and Es Coloms Cave, located in a natural area without anthropogenic pressure, show moderate chloride concentrations with the same distance from the coast as the previous examples, and in the latter case, even freshwater in vertical hydrochemical stratification. Therefore, a common variable in most aquifers is

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human pressure, summarized in two factors: groundwater pumping and discharges of untreated water. In this context, it is important to highlight a crucial difference in the vertical variability of the interface: in the coastal aquifers of eastern Mallorca, the interface begins in the brackish zone, with no presence of a freshwater zone. These findings contribute to a better understanding of the dynamics of the interface in coastal aquifers and have significant implications for the sustainable management of water resources in the context of Climate Change.

Keywords: brackish zone, climate change, coastal karst aquifers, groundwater

Combination of stochastic and analytical modelling methods for the prediction of climate change impact on spring discharge

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Abstract

A novel modelling approach has been developed for the prediction of spring discharge time series based on regional climate model projections. This approach integrates the advantages of traditional stochastic methods such as regression analysis with physics-based analytical baseflow models.

During the stochastic modelling of karstic spring discharge, hydrograph peaks usually show a reasonable correlation with daily rainfall data, but spring baseflow has insufficient correlation with rainfall. This is a direct consequence of the physical functioning and the dual hydraulic behaviour of karst. While hydrograph peaks (flood) originate from direct recharge into the aquifer, baseflow originates from the release of water infiltrated into and stored in the low permeability matrix blocks. Baseflow is temporally delayed compared to rainfall and discharge peaks. For this reason, it is not possible to adequately describe these two different physical processes with one regression function. While flood discharge peaks can be approximated through the application of regression functions between rainfall and peak discharge, the description of baseflow requires the application of physics-based analytical functions.

A novel combined stochastic-analytical method was developed for the characterization of spring hydrographs based on measured daily rainfall data.

The combined modelling method involved the establishment of regression functions between rainfall and discharge peaks, and the simulation of flood discharge based on future rainfall time series predicted by regional climate models.

Composite exponential formulae (Forkasiewitz and Paloc 1967) were applied for describing baseflow, where fitting parameters were calibrated based on historical rainfall and discharge data.

A combined stochastic-analytical modelling of discharge hydrographs was undertaken on various karstic springs located at the Durmitor National Park in Montenegro, and at the Aggtelek National Park in Hungary.

Regression functions between rainfall and discharge were established using historical data. Baseflow recession was described using a multi-component exponential model, where parameter fitting was performed on Master Recession Curves. Rainfall time series from Regional

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Climate Model scenarios were applied to predict future discharge time series.

The applied method is suitable for simulating the temporal distribution and magnitude of discharge peaks and for the simulation of baseflow recession. The applied model scenarios predicted the probability and magnitude of discharge which were represented through Flow Duration Curves.

Keywords: Spring hydrograph, stochastic model, analytical model, climate change

Combining hydrogeological, geophysical and geochemical approaches to investigate the role of weathered zones on karst water resources

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Abstract

The objective of this work is to revisit the conceptual model of karst aquifers accounting for weathered zones, using multidisciplinary and multi-scale approaches (hydrogeology, geophysics and geochemistry). We hypothesise that the weathered zone plays a key role on water transfers and storage.The study site is the karst aquifer of the Durzon spring, located in South of France, under a Mediterranean climate. The recharge area is about 110 km^2 and is mainly composed of dolomitic rocks characterized by large weathered areas. The recharge occurs by diffuse infiltration, leading to an inertial response of the spring. First, to acquire the spatial information of weathered zones, we used a geochemical method at the rock sample scale with porosity calculations, XRF, XRD and SEM analysis. At the local scale (hundreds of meters), we used geophysical methods with electrical resistivity tomography and seismic refraction tomography. These methods were performed to describe and identify the geometry of the weathered and the un-weathered zones. Second, to characterize the evolution of the water body over time, we used geophysical monitoring (gravity) and hydrogeological survey (piezometry in 3 boreholes and discharge in 4 cavities and at the outlet). Third, to make a link between all water bodies characterized by the different time series (piezometric, discharge, and gravity time series), we applied a black-box modeling approach using Tempo software (© BRGM) .Regarding spatial characterization, our results show that dolomite alteration corridors are present over the first hundred meters of the unsaturated zone. In these zones, the samples have a porosity of up to 50% and can therefore contain more water than in the un-weathered rock. Regarding temporal analysis of rainfall and discharge signals, correlation analysis evidence contrasted contributions of fast (piston effect) and slow flow according to sites and scales. Regarding temporal analysis, results show that gravity and piezometry signals in the unsaturated zone have the same pattern, linked to the seasonal

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recharge. Globally, this study illustrates that an interdisciplinary approach provides informations on different hydrogeological compartments, that are necessary to build a valuable conceptual model. As a conclusion, it shows that weathered rocks in the unsaturated zone of karst aquifers can play a key role in their overall hydrogeological functioning.

Keywords: hydrogeological, geophysical, geochemical, weathered zones

Comparison of process-based models to machine learning techniques in the simulation of flow in complex karst systems: Application on semi-arid case studies in Lebanon

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Abstract

Flow and recharge in karst groundwater resources are often challenging to simulate due to the complexity of dual flow and infiltration processes. Therefore, predicting spring responses relies heavily on climatic input and an understanding of infiltration processes within the unsaturated zone, epikarst, and flow.

In this proposed work, we aim to integrate various approaches, including process-based, statistical, and machine learning techniques, to simulate flow in monitored karst systems. High-resolution spring and climatic time series have been collected since 2014 (with limited data since 2011) from two karst catchment areas within the Nahr el Kalb water basin (Qachqouch and Assal Springs) in a semi-arid snow governed region in Lebanon. Building on insights from the process-based approach, our plan is to explore machine learning algorithms to uncover nontrivial interdependencies between monitored parameters and dependencies on listed co-variates and control parameters.

The input data were inputted into Convolution Neural Networks (CNN) and Long Short-Term Memory (LSTM) approaches, with hyperparameter tuning and appropriate filters, to compare their precision in reproducing output data and assess their improvements over the process-based approach. Preliminary models aim to replicate discharge at the spring from different input signals, including low-cost monitoring parameters such as electrical conductivity, temperature, and turbidity time series.

Optimizing the performance of these models presents the challenge of finding the best hyper-parameters, along with structuring and selecting the appropriate input data. Preliminary trials were conducted to simulate next-day spring discharge using LSTM architecture. For El Qachqouch and El Assal springs, a simple LSTM model employing the previous three values of discharge with few layers showed NSE (Nash Sutcliffe coefficient) scores of 0.84 and 0.9, respectively. Further experiments with varying input sizes and more complex architectures are being conducted (different activation functions etc.).

In an attempt to model rainfall-runoff using a CNN, previous precipitation values and a

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*Speaker

simple CNN architecture were employed to predict the next-day discharge value for the El Qachqouch data, resulting in an NSE score of 0.4. Subsequent adjustments will focus on refining both input parameters and the architecture to achieve improved predictive performance.

The results were compared to the discharge output of a semi-distributed linear reservoir calibrated numerical model for the complex catchment of El Qachqouch spring, and to an integrated distributed equivalent porous media calibrated model for El Assal spring system.

Coupling PEST and LuKARS 2.0: Merits and limits of automatic parameter optimization

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Abstract

Hydrological models are fundamental tools to investigate the system functioning and therefore support sustainable management of karst water resources. Due to limited knowledge about the subsurface, karst hydrological models need to be calibrated, most commonly against discharge time series observed at the karst spring. However, the calibration procedure, if not automatized, can be tedious and time consuming. PEST (Parameter ESTimation (Doherty, 2010)) is a model-independent parameter estimation and uncertainty quantification tool which is widely used for optimizing parameters in hydrological models. PEST provides a versatile iterative calibration process which can be applied to various hydrological models regardless their structure and complexity by directly interacting with the models' input and output files.

In this study, we couple PEST with the semi-distributed conceptual model LuKARS 2.0 based on the original Land use change modeling in KARSt systems (Bittner et al., 2018), which lumps the catchment into hydrotopes with individual hydrological properties. Each hydrotope is characterized by a specific response time and contributes both to the slow infiltration Qis (m3/s) into the matrix and to the fast flow through the conduit $Qhyd$ (m3/s). LuKARS 2.0 allows a flexible conceptualization of karst systems by accounting for the water contributions draining from the main geological areas (hydrotopes) in the watershed. In addition, a transfer between matrix and conduit QMC (m3/s) was implemented in the lower compartment of the model following the approach proposed in KarstMod (Mazzilli et al., 2023; Sivelle et al., 2023) as function of the discharge coefficient kMC (mm/h), exponent aMC (-) and water levels in the matrix M and conduit C (mm). The calibration of model parameters is based on hourly discharge time series. As a benchmark, we consider synthetic scenarios to exclude potential errors in the model structure and input data. The optimization procedure was then tested with real data at the Baget karst system (Pyrenees, southern

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France) characterized by the coexistence of karst and non-karst areas.

Our investigation shows that the PEST algorithm effectively identified optimal parameters for the LuKARS 2.0 hydrological model using artificial data. In the application to the real case study, we show that the optimal solution obtained based on spring discharge observations may not be consistent with hydro-chemical observations. Time series at hourly resolution of the contributions of HCO3- and SO42- to the total electrical conductivity, derived by Richieri et al. (2023), contribute to the description of the internal dynamics of the Baget system, i.e., the response of water contributions from different geological areas in the catchment to different flow conditions. Our fundings show that the PEST optimized parameters well represent the discharge at the spring but not the variability of the internal fluxes, i.e., water contributions from the karst and non-karst area.

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Defining of karstification depth beneath dam sites using special investigations methods (the Višegrad dam example, Bosnia & Herzegovina)

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Abstract

In respect of risk factors in dam and reservoir construction in karst, particular attention must be paid to reservoir water tightness. An appropriate project concept, prior to exploration, can significantly reduce the risks or minimize them to acceptable levels, while the reductions of exploration work can increase them. Some of the inadequately explored reservoirs constructed in karst have never been fully filled up with water or losses of water increased significantly over time (as in the case of the Višegrad dam). Already in the first years of the exploitation of the Višegrad dam, the occurrence of submerged down streams springs was observed. The number of springs varied during the period of exploitation; occasionally some smaller springs merged into a larger one; the change of the location of the springs also occurred as well as the frequent appearance of muddled water on the surface that indicates that washing out of caverns is still in progress. The measurements of water quantities that appear in the springs downstream from the dam revealed that the quantity had increased from the 1.4 m3/s (in the year 1990) to 13.92 m3/s (in the year 2008), and even 14.68 m3/s (in the year 2009). Since it was established that this is a highly undesirable phenomenon, and that the increase of water losses can lead to a variety of damages, it has been decided that it is necessary to perform a certain number of special-purpose investigations. One of top priority investigation was defining karstification depth and development beneath dam site aiming to facilitate the dam's continued use and develop rehabilitation strategies related to seepage. One of the main parts of karstification research was drilling of 16 boreholes. This paper summarizes results of tracer tests, deep underwater investigations, borehole videoendoscopy, core logging, geophysical logging etc. which led to conclusions related to the spatial analysis and speleogenesis of karst features under the dam sites.

Keywords: karstification depth, reservoir and dam in karst, water losses, rehabilitation strategies

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Design in seasonal karst springs for sustainable water management in semi-arid karst regions

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Abstract

Karst springs have always been very important water resources for many Mediterranean civilizations throughout history. There is a vast amount of hydraulic structures such as irrigation canals, qanats, cisterns, cave pools, and aqueducts in the karstic regions of the Anatolian peninsula. From the historical to the modern era, the scale of these engineering projects has increased by the increase in population and water demand. Both increasing water demand and decreasing water quantity will result in an increase in the pressure upon karst groundwater particularly in the semi-arid climate regions. In this respect, seasonal karst springs are in a very crucial position that drains the karst aquifers in wet seasons - when water demand is relatively lower- and dry in the dry seasons -when water is needed, especially for agricultural irrigation. To find an efficient management solution to this problem, we conducted hydrodynamic, hydrochemical, and speleological investigations on the possibility of building a cave dam with all its advantages and drawbacks in the Central Taurus Karst region. According to our observations, there is no evidence of cave fauna and flora in Güvercindeliği Cave, and our calculations showed that building a dam has the potential to store approximately 4 million m3 of water in and surroundings of the cave and conduit system. By doing this, we aim to increase the backwater level up to 60 m above the discharge elevation of the seasonal Pinarbaşi karst springs and have the flexibility for the residents to consume the stored water for domestic use, animal livestock, and agricultural irrigation in dry periods.

Keywords: Karst hydrogeology, Cave dam, Sustainable water management, Drought

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Development and application of the hybrid modelling approach by combining process-based and machine-learning models for karst groundwater systems

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Abstract

Karst aquifers are important for freshwater supply but difficult to manage, due to highly variable water levels and spring discharge rates. In the past, different modelling approaches such as process-based lumped models, physics-based distributed models and data-driven (e.g., machine learning) models have been implemented for karst systems to simulate their highly variable drainage and discharge behaviour. However, all these approaches have drawbacks or advantages in terms of observational data requirements, model parameterisation and model evaluation process. In addition, adequate prediction of the discharge behaviour of karst aquifers under extreme flow conditions is becoming increasingly important as extreme events such as droughts and floods become more frequent but remains technically challenging and requires further research and development. In the current study, we have explored the potential of integrating two different modelling approaches for more accurate and robust modelling results. Such a hybrid modelling approach by combining process-based and machine learning models requires a special architectural design in terms of internal information flow between the models. In this study, we would like to present a first conceptual development of possible hybrid model structures and demonstrate the application of a newly developed hybrid model for a large and well-studied karst catchment in Slovenia, with a focus on the simulation of discharges under extreme flow conditions.

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Establishment of a holistic hydrological monitoring network in a karst critical zone

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Abstract

Studies that evaluate the role and significance of environmental changes in karst aquifers, including precipitation, evapotranspiration and infiltration regimes, affected by changes in soil and vegetation cover, are important for understanding hydrological relationships to groundwater recharge. They are essential due to the important role of karst water resources for freshwater supply and the conservation of the rich and unique biodiversity of the subterranean aquatic ecosystem. However, the special characteristics of water flow in karst areas make it difficult to understand groundwater recharge. This is all the more true as measuring and sampling systems in karst areas are challenging and require special development and adaptation. This work presents the monitoring network of groundwater recharge and mass transport through the vertical profile of the karst aquifer, i.e. the karst critical zone, which comprises the atmosphere – vegetation – soil – unsaturated – saturated aquifer zones. In the Postojna-Planina Karst area in SW Slovenia, we have established a total of 21 detailed observation sites on the surface and in the underground. At the surface sites, we carried out a detailed inventory of vegetation types and soil properties. Using specially designed equipment, we have established continuous monitoring of open field precipitation, throughfall, air and soil temperature and soil moisture, as well as monitoring of flow and level of cave seepage, sinking streams, underground streams and springs, water temperature and electrical conductivity. During precipitation events, we observed the transfer of soluble and insoluble contaminants through the karst aquifer more closely. We provide insights into the strengths, weaknesses, limitations and opportunities of the established monitoring network. The experience gained represents a new contribution to the field of karst hydrology and a globally unique approach to a topic of great interest.

Keywords: karst aquifer, measuring and sampling, groundwater recharge, mass transport

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First results to simulate flow through a statistical karst and fault network using an original karsts statistical model

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Abstract

Water resource management poses a substantial societal challenge, exacerbated by the continuous effects of climate change. Karst aquifers represent substantial reserves of freshwater in various regions of the world and a non negligeable part of the European soil; however, their exploitation is constrained by their complex behavior. A comprehensive understanding of flow in karstic aquifer requires the establishment of models, but the modelling of karstic system is one of the biggest challenges in geosciences. Characterizing and modeling this type of aquifer requires the study of three interacting levels of heterogeneity: matrix, faults and fractures, and karst conduits. Conventional single or double-medium approaches, based on homogenization and a Darcy-type flow model, fall short in considering the triple media aspect and assume a Darcy-type flow in the karst conduits. However, the dimensions of these conduits can induce inertial flows that must be considered.

The main difficulty is to build a statistical model to characterize the karst impact on flow dynamics. The method proposed by Verscheure et al. (2012) characterizes the fault network and models the sub-seismic faults while maintaining geological consistency with seismic faults. Stochastic karst networks are derived from these faults network. This approach captures the spatial fault organization thanks to a fractal dimension.

The aim of the presentation is firstly to present the statistical model for the generation of karst networks. Secondly, the flow model based on an embedded model depicting the entire karst will be discussed. At this step, flow resolution is still determined using Darcy flow model tailored to karst conduits but will be improved in the future.

Finally, first results based on this distributed model are compared to a lumped model on validation cases. However, this approach highlights the importance of using multi-disciplinary

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approaches in the process of modeling flow in karst systems.

VERSCHEURE, M., FOURNO, A. & CHILES, J.-P. Joint Inversion of Fracture Model Properties for CO 2 Storage Monitoring or Oil Recovery History Matching. Oil & Gas Science and Technology – Revue d'IFP Energies Nouvelles 67, 221-235. ISSN : 1294-4475 (2012).

Keywords: Karst, Conduit network, Stochastic simulation, Geological modelling, Faults and fractures modelling, Distributed modelling

Flash flood and vigilance forecasting of a complex, anthropogenic karst hydrosystem using neural networks. Application to the Las coastal river at Toulon (South-East France)

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Abstract

Karst aquifers are complex, difficult to observe and poorly understood. Modeling and forecasting hydrodynamic variables to help manage floods and low-water periods are important operational issues, for which there are currently no satisfactory solutions. Indeed, physical hydrodynamic modeling methods require extensive in situ measurements to optimize the models, and make it difficult to take into account multi-scale phenomena and non-stationarity. Machine learning models, on the other hand, can learn a relationship linking input and output variables, which are not necessarily the state variables of the physical relationship. For example, groundwater level can be used as well as discharge. In previous work, it has also been shown that multilayer feedforward perceptron-type models can take non-stationarity into account (Taver, 2015). In the present work, we therefore propose to use machine learning methods to simulate and predict the behavior of a karst hydrosystem during flood events.

The study site is the Las River at the Lagoubran station in Toulon (180,000 inhabitants, south-east France). The site is particularly complex and difficult to observe. It therefore enables us to assess the potential of statistical models to represent the flow in a measurement environment that would make it very difficult to adopt any other approach. The Las river is 8 km long, starting at several springs: the Dardennes springs and the intermittent Ragas spring, and discharging in the Mediterranean Sea. Its catchment area is estimated at 70 km^2. Spring's water comes from the Siou Blanc karstified limestone plateau. These springs flow into a dam dedicated to the storage and abstraction of drinking water. Dam's overflow returns to the river, which partly infiltrates again. Downstream, the Las River receives the Saint Antoine spring's water, part of which comes from Las River infiltration itself. The Las River also collects urban runoff from about a 12km^2 subcatchment.

The difficulties of the study are as follows: an approximately defined karst bassin area, fast-moving urban water inflows, loss of the Las River, which joins it downstream via the Saint Antoine spring, perturbation of flows by the presence of the dam and abstractions for drinking water. The Las, with flows of up to 40 to 80 m3.s-1, crosses Toulon, partly underground, and thus causes overflows that are more significant as the urbanization of the city

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of Toulon increases. Flood forecasting therefore represents a major operational challenge. The work consists in an in-depth correlative analysis of the various variables available at different time steps (from 15 min to 1 day), between September 2012 and October 2017, a spectral analysis, and the creation of neural network-based models to simulate and forecast floods at the Lagoubran station, but also to create a classification model to determine vigilance levels. It has been shown that the latter approach enables a longer forecasting horizon to be achieved.

Keywords: water management, Water, Groundwater, Neural network, Forecasting, Flood, Runoff, Urban stream, Karst spring, Bay of Toulon

Flow, transport and karstification model of the Buda Thermal Karst, Hungary – theoretical and practical consequences

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Abstract

The regional groundwater flow concept can apply to basin-and-range areas, mainly confined and adjoining unconfined carbonate regions. In this approach, we handle aquifers and aquitards forming half-basins as a groundwater system, supposing hydraulic continuity (Tóth 1995, Mádl-Szönyi 2017; Mádl-Szönyi et al. 2022). Owing to long-term research activity in the natural laboratory of the Buda Thermal Karst (BTK), a new conceptual model was established to explain comprehensively different processes like groundwater flow, heat transport, and hypogenic karstification. We applied research methods to create a conceptual model, including spring and hydraulic data analysis, numerical flow and heat transport simulations. In the presentation, we characterize regional groundwater flow in the BTK by the driving forces, recharge and discharge areas and different flow systems based on regional scale hydraulic data analysis (Mádl-Szönyi et al. 2019; Czauner et al. 2022). We determined various flow components of meteoric and basinal fluids based on chemical and isotopic data (Eröss et al. 2013). Numerical simulations displayed the system's geological evolution, influencing the dominance of different driving forces, flow systems and components (Havril et al. 2016). Based on a comprehensive interpretation of measured data, we could set up a 2D numerical flow and heat transport model to characterize different orders of flow systems. In addition, we could simulate advective heat transport and buoyancy-driven flow (Szijártó et al. 2021). By collecting literature data and observations from well-logs, we could fit different karstification processes in the distinct parts of the system. The new conceptual model is applicable not only for the Buda-Thermal Karst but also for similar basin-and-range areas as it has demonstrated for Hungarian (Mádl-Szönyi et al. 2022) and further regions of the world (Wang et al. 2016; Andreo et al. 2016; Pérez-Quezadas et al. 2017; Yang és mtsi. 2019; Sracek et al. 2019). Based on the comprehensive understanding of the processes, we could reveal biogeochemical precipitates around thermal springs, and we could determine the origin of its high 226Ra content from the basinal fluids, responsible for the elevated 222Rn content of thermal springs (Eröss et al. 2013, Kovács-Bodor et al. 2019). In the confined half-basin, we have identified an interface resulting from the vertical superposition of flow systems, which is a "mixing zone" for fluids of different salinities and a potential hypogene karstification zone (Mádl-Szönyi and Tóth 2015; Mylorie and Mylorie 2007; Sanz et al. 2011). In the Buda thermal karst, the known vertical channel systems are attributed to the upward and downward flow of water in convection cells, as demonstrated

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*Speaker

by numerical modelling, a process that has been of decreasing importance on the geological timescale since the late Miocene (Havril et al. 2016; Szijártó et al. 2021). The results provide background for the enhanced utilization of thermal water for spas and geothermal purposes. The research is funded by the National Multidisciplinary Laboratory for Climate Change, RRF-2.3.1-21-2022-00014 project.

Keywords: regional groundwater flow, numerical, karstification, thermal, Buda Thermal Karst

Geological risk analysis of geothermal developments in a karstic environment

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Abstract

Paleo-karst systems are often focus of geothermal utilization, thanks to their favourable flow pathway network. However, their complicated geological setup is associated with significant heterogeneity in permeability distribution resulting in exploration uncertainty. In this research we develop a novel methodology to analyse and quantify the geological risk of geothermal developments. The new approach is adapted from the petroleum industry and follows the risk assessment scheme of petroleum play analysis. The methodology is first tested in a study area located in north-east Budapest, Hungary. Here neogenic siliciclastic sediments cover Triassic carbonates which serve as thermal water reservoir. In this region, historically outstanding thermal wells and projects have been drilled and developed, however, several unsuccessful attempts also occurred due to geological uncertainty, lack of knowledge and proper pre-analysis. To estimate whether a future geothermal system is able to provide sufficient capacity, in this study probability of success is assessed by evaluating potential geological risk factors which can hinder the geothermal production and reinjection. The multicriteria analysis is done by combining and evaluating datasets on aquifer quality, temperature and flow conditions using among others lithological data, cavity, temperature-elevation as well as pressure-elevation profiles. The outcomes of the research help in decision-making while preparing new geothermal developments. This research was supported and financed through the KDP-2021 Cooperative Doctoral Programme of the Ministry of Culture and Innovation of Hungary from the source of the National Research, Development and Innovation Fund, grant number: KDP 2021 _ELTE_C 1789026. The research was funded by the National Multidisciplinary Laboratory for Climate Change, RRF-2.3.1-21-2022-00014 project.

Keywords: paleo, karst, geothermal, geological risk, thermal water, uncertainty

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GROUNDWATER RESOURCES DIMINISHING IN MOUNTAIN AREAS: ONLY CLIMATE CHANGE OR ALSO A "HIDDEN" CONSUMER? AN EXAMPLE FROM CENTRAL APENNINES (ITALY)

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Abstract

In recent years, the evaluation of water resources is acquiring ever greater importance mainly due to the world population growth, especially in areas like the Mediterranean region where rainfall has shown a generally negative trend, also characterized by shorter and even more intense events. Furthermore, the ever-increasing demand for high-quality drinking water highlights the importance of correct monitoring and careful management of the resource. The area of the Sibillini Mountains National Park, located in the central Apennines (central Italy), proves to be particularly suitable for a quantitative study of the water resource due to the excellent water quality widely exploited for drinkable uses.

This sector of the Apennine ridge is characterized by suspended aquifers, even of large dimensions, and by a deep basal aquifer hosted within fractured and karstified micritic limestones.
The monitoring, in some cases for decades, of the discharges emerging from some important spring systems and of some river reaches that drain the waters circulating within the basal aquifer has highlighted a constant and progressive decrease in stored water resources. This phenomenon, as mentioned, is certainly linked to the rainfall trend recorded in recent decades which, especially concerning the time of residence of the snowfalls on the ground, has shown a marked decrease. However, the role played by the strong increase in forest cover along the recharge areas within the carbonate ridge over the last 50-60 years is underestimated. The lower infiltration linked to the consumption of trees, especially in the summer season, combined with the amount of precipitation lost through interception or evapotranspiration phenomena, has been shown to reach values in places higher than 25-30%.

Keywords: hydrogeological budget climate change karst aquifers vegetation cover evapotranspiration

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Hydrogeological and physico-chemical signatures to characterize flood flows in a Mediterranean urban karst aquifer (Fontaine de Nîmes spring, France)

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Abstract

Hydrological signatures are metrics that quantify different aspects of global hydrological behaviour (e.g. magnitude, extremes, timing of flow condition). In the case of karst aquifers, the high degree of variability of their hydrogeological response makes it difficult to generalise a single hydrogeological signature for a given site. Adding physico-chemical variables to hydrological signatures provides thus new opportunities to better understand the variability of their responses to rainfall events. The goal of this paper is to provide a methodology for characterizing water origin and transfer in karst aquifers at the flood-event timescale, by using an analysis of various high-frequency physico-chemical signatures that describes transfer of dissolved and suspended particulate matters. We computed descriptors of the physico-chemical time series, including discharge (Q), electrical conductivity (EC), turbidity, and natural fluorescence (NF) of water. The study site is the Fontaine de Nîmes karst observatory (southern France), which is located in an urban and Mediterranean environment. On the basis of 27 major flood-events, we propose a flood typology based on hydrological conditions. We characterized pre-event and event water using EC changes as they reveal water residence time in karst. EC dilution depends linearly on peak flow (-100 μS/cm for +6 m3/s), suggesting that a mixing process by surface waters controls most of the hydrochemical response. Turbidity peak amplitude (0-150 NTU) depends on both peak of first derivative of Qand flood type. NF peaks are found to be inversely proportional to initial discharge rates, except for summer events. A quantification of the contributions of 3 compartments (surface waters, unsaturated zone, and saturated zone) to spring discharge was performed on each flood-events using an End-member mixing analysis performed using EC and NF signals. Results showed that the saturated zone is the main contributor for all flood events, but that contributions of the 3 compartments (60-80% for unsaturated zone; 5-20% for surface waters; and < 5% for unsaturated zone) vary according to flood typology. We propose also a framework to identify the origin of water turbidity by means of informations on various signatures: pre-event and event water contributions (EC), intensity of sediment mobilisation (peak of first derivative of discharge), unsaturated zone contribution (natural fluorescence peak). The main results show that flood events with the highest turbidity peaks (> 120 NTU) mobilise pre-event and event waters equally, and are characterized by relatively "young" age water during high water levels period. Flood events with lower

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turbidity are characterized by pre-event waters of more or less older age according to the season. Overall, this work highlights the benefit of combining physico-chemical signatures in addition to hydrogeological ones to better characterize processes in complex aquiferss.

Keywords: Flood typology, unsaturated zone, urban area, physico chemical signatures, water origin

Hydrogeological Characterization of Timau Devonian Karst Aquifer (NE Italy)

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Abstract

In the north-western sector of the Friuli Venezia Giulia Region, on the border between Italy and Austria, there is one of the most important karst springs in the Alps, the Fontanon of Timau. It has a discharge ranging between 250 and 5000 l/s and due to its high flow rate, it is exploited both for drinking and hydropower purposes.

The area is characterized by the presence of a complex Paleozoic sequence of low permeability units as claystone, siltstone, sandstone, followed by a thick succession of permeable karstified limestone closed on the top by a turbiditic succession, almost impermeable. The steep and impervious area is characterized by the presence of several caves with a predominant vertical development allowing a quick infiltration of the effective precipitations. In order to understand the hydrogeology and to define the recharge area of the Fontanon di Timau a research project, partially funded by the Geological Survey of the Friuli Venezia Giulia Region was realised. During the 5-years project, detailed geological, hydrogeological surveys and geochemical monitoring of precipitations, springs and surface waters were carried out. Temperature, Electrical Conductivity, major ions (anions and cations) and trace elements as well as the environmental isotopes (d18O, d2H), tritium (H3) and radionuclides (Rn) were analysed in different hydrogeological conditions. Adjoining, temperature, water level and electrical conductivity of specific water points were acquired in continuous by using CTD probes.

From the data analyses of the in continuous monitoring, emerge that the spring is characterized by rapid increase of its discharge coupled with a decrease of the electrical conductivity, behavior attributable to a highly effective drainage, typical of a mature karst system. Isotopes and trace element results highlight that the spring is recharged not only by the surrounding areas of Pal Piccolo and Creta di Timau watersheds, as previously thought. Most part of the recharge comes from the massifs of Mount Coglians and Creta di Collinetta westerly of the But River. A third contribute is due to the waters which infiltrate in Austrian territory, beyond the superficial watershed. The connection between the western sector of Mount Coglians-Creta di Collinetta and the Fontanon di Timau were also verified by dye tests using uranine and tinopal.

Forthermore the Fontanon di Timau, in the area are present some other springs characterized by definitive lower flow rates. They are all recharged only by neighboring basins limited to the Italian side.

The obtained results are of considerable importance in the conscious management of the cross-border resource and its protection.

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Hydrogeological framework of minor aquifers in Central Italy (Alto Sangro area) and potentialities' assessment for drinking purposes

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Abstract

Drinking-water supply in high altitude villages in central Apennines is ensured by springs with a limited and seasonal discharge. These allow villages self-sufficiency with some summer deficit in water availability because they can not take advantage from lower elevations' springs which are used for coastal areas supply.
In the Alto Sangro area, that includes the south-eastern portion of the Abruzzo region's mountain area and the north-western part of Molise region, many springs located at altitude higher than 1000 m are tapped for drinking purpose. However, their use is still limited because of the managing companies' exploitation and distribution strategies; in fact, investing in springs or well fields with major potentials is preferred, even if a more energetically demanding for water distribution is required.

In this work, features, potential and residual capabilities of these aquifers have been highlighted and described. The structural set-up is peculiar: tectonic relationships between formations occur mainly through faults and low angle thrusts, which put in contact terrigenous lithologies with different permeability (i.e. *Gamberale-Pizzoferrato formation*), within the so-called "*coltre molisana*", with the terrigenous - carbonatic succession of the central Apennines and the *Sicilidi* calcareous-clayey formation.

The complex stratigraphic and tectonic relations between these formations allow groundwater to emerge as springs (discharge between 1 l/s and 2 l/s), which are mainly classified as "for *permeability limit*" (Civita, 1973). The *coltre molisana*'s calcarenites or the Apennines limestone formations usually represent the calcareous hydrogeological complex, while the aquiclude correspond to the clayey complex of the *Sicilidi* or the *coltre molisana*'s clay. Sometimes, the coarse slope deposits serve as aquifers, too: they come from carbonate deposits located at higher altitude, and lie over impervious complex.

The first results about groundwater potentialities of these high-altitude springs, have been obtained through infiltration coefficient and it shows recharge volumes of about 100 Mm3, over a 615 Km2-wide area; this can be coupled with numerical modeling, using MODFLOW with Model Muse interface, for a more accurate quantification.
- Civita M. 1973. Schematizzazione idrogeologica delle sorgenti normali e delle relative opere di captazione. Memorie e Note Ist. Geol. Applic. Napoli, 12, pp 1-34.

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HYDROGEOLOGICAL KARST BEHAVIOR IN A CONGLOMERATE AQUIFER IN VENETO REGION (NE ITALY)

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Abstract

The Montello anticline is a morphotectonic feature of the east piedmont of the South Alpine Chain in northern Italy, approximately 40 km northwest of Venice, Italy. This whaleback-shaped hill is mainly composed by Mio-Pliocene calcareous conglomerates. Due to its particular tectonic evolution, the Montello might be divided in two different sectors characterized by different karst rates. The eastern sector is the most interesting as it shows an old and well-developed karst system. In such an area three karst springs known as "Casselon", "Tavaran Lungo" and "Forame" were monitored from 2019 to 2022 using multi-parameter sensors, measuring water level, temperature, and electrical conductivity at hourly intervals. Analyses were conducted in the R environment using Flow Duration Curves (FDC) to assess the degree of karstic development, autocorrelation functions (ACF) to measure the "memory" effect of springs, and cross-correlation functions to analyze the relationships and time delays among monitored parameters. Additionally, rainfall data was compared with water levels to estimate travel times. Subsequently, a rough classification of springs (replacement, piston, homogenization) was defined using the correlation coefficient within the VESPA index. The VESPA index also facilitates the classification of spring vulnerability.

In particular, the "Casselon" spring exhibits a highly karstic behavior, with a decorrelation at a lag of 300 hours (equivalent to 12.5 days), and a cross-correlation function (CCF) between water levels and electrical conductivity (EC), suggesting a replacement behavior. The CCF between rainfall and water levels indicates the spring's response to recharge within 3- 4 hours. The springs vulnerability assessment suggests a very high vulnerability level.

The "Forame" spring, on the other hand, shows a decorrelation at a lag of 600 hours (equivalent to 25 days), which is more delayed than "Casselon". The CCF between water levels and EC displays a replacement behavior, with a spring response to recharge within 3-4 hours. The vulnerability assessment indicates very high vulnerability level.
Lastly, the "Tavaran Lungo" spring demonstrates a less pronounced karstic behavior compared to the previous two springs, with a decorrelation occurring at a lag of 1000 hours (equivalent to 40 days). The CCF between water levels and EC shows a replacement behavior and the CCF between rainfall and water levels indicates a spring response to recharge

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within 3 hours. The correlation coefficients reveal a weak replacement behavior, while the correlation factor suggests replacement and piston behavior, respectively. The vulnerability assessment results indicate a high vulnerability level, albeit with lower values compared to the "Casselon" and "Forame" springs.

Impact of more than thirty years of intense exploitation on groundwater flow system and chemistry of a carbonate karst aquifer in a semi-arid region. The case study of Sierra de Humilladero (Málaga province, S Spain)

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Abstract

In water-stressed areas such in S Spain, non-continuous outcrops of carbonate rocks hold limited groundwater volumes of good quality that very often constitute the only source of water for urban supply. Population growth and extensive agriculture during the last decades are the major threats over groundwater. Aquifer overexploitation, related to uncontrolled pumping, results in most cases in the substantial modification of the groundwater flow distribution, leading to water quality impairment and associated aquatic ecosystems degradation. In the present research, the small carbonate massif of Sierra de Humilladero (Malaga province, S Spain) has been selected to quantitatively address the impact of intensive pumping during more than thirty years on the groundwater flow scheme and chemical status of the aquifer system. From a geological standpoint, the permeable formation is constituted by an isolated block of Jurassic limestones and dolostones lying over a clays and evaporites formation from the Triassic basement and is mainly surrounded by Miocene sandstones and alluvial deposits of Quaternary age. To achieve the main research goal, a compilation of historical data (piezometric levels and chemical composition of groundwater) from public databases and technical reports, as well as collection of new hydrogeological data from several field surveys have been conducted. After an exploratory analysis, a spatial-temporal piezometric study together with a tentative End Member Mixing Analysis (EMMA) were performed to quantify and timely assess the input source contribution from surrounding aquifer formations to statistically support the hypothesis launched by precedent authors. Results show that intensive groundwater exploitation has provoked a sustained lowering of piezometric levels (3-4m/year), up to 93 meters since 1998, along with a dramatical groundwater impairment, promoted by hydraulic gradient inversion effect with surrounding permeable/karstifiable geological formations (Miocene and Triassic formations). It is also observed that the original calcium-bicarbonate chemical type of karst groundwater turned to sodium-sulphate-chloride facies while maintaining relatively high NO3- concentrations, showing two marked hydrogeochemical trends. After iterative performance of statistical-based mixing analysis, a three-component mixing modelling framework (representing distinctive chemical signature of Jurassic, Miocene and Triassic groundwater) was proposed using six conservative/reactive chemical compounds. Comparing piezometric data and computed end-member

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mixing fractions, three stages in groundwater quality evolution have been differentiated: stage 1 (1992-2010), characterised by the influence of the chemical signature of Miocene waters (1-9% mixing ratio) in sampled karst groundwater, coinciding with the period of maximum rate of piezometric lowering ($>$ 5 meters/year); stage 2 (2011-2016), denoted by the progressive mixing with evaporite groundwater from Triassic substratum (up to 20% in 2016) at depth (380-360 m a.s.l.), as the overexplotation effect on piezometric levels kept decreasing but was less intense than in stage 1, and; stage 3 (2018-today), in which pumping rate was reduced and chemical types are not clearly defined (random mixing fractions). Despite the limitations of the available data and statistical methods applied, understanding not only the groundwater imbalance but also the major mechanisms causing loss of groundwater quality is of undoubtable relevance to suitably protect and manage water resources under increasing water quotation demand and climate change future scenarios.

Keywords: Aquifer overexploitation, karst groundwater, flow and hydrochemical changes, aquifer management, S Spain

Impact of soil coverings and land cover types on groundwater recharge in Karst Aquifers of Southern Italy

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Abstract

Karst aquifers are the most prevalent and relevant aquifer types in the Mediterranean areas and are fundamental for providing groundwater resources to the region. From a global perspective, karst aquifers supply about 10-20% of the world's population with drinking water, despite being vulnerable to droughts and pollution scenarios. In southern Italy, particularly in the Campania region, karst aquifers are the main source of drinking water, supplying the principal regional aqueduct systems. These aquifers are characterized by unusual surficial geological conditions due to the widespread occurrence of a soil mantle, mainly of ash-fall pyroclastic origin, and the development of related land cover types. This particular condition plays a significant role in hydrology, although its control over groundwater recharge has been oversimplified and underestimated. Therefore, advancing the assessment of groundwater recharge in these aquifers is a major scientific challenge in order to estimate groundwater availability, especially in the perspective of the impacts of climate change. Here, we present a methodology based on field and laboratory characterizations, as well as modeling approaches, to enhance our understanding of groundwater recharge processes. At this scope, the Soprano-Vesole-Chianello Mts. karst aquifer (Campania region, southern Italy) was selected due to its geomorphological settings and variability of soil cover and vegetation types, which were recognized as typical of Mediterranean karst aquifers. A comprehensive characterization of the soil mantle was developed, considering different land cover classes, measurements and stochastic spatial modeling of soil thickness. The unsaturated hydraulic properties of undisturbed soil samples were analyzed by laboratory tests resulting in the determination of Soil Water Retention Curves (SWRCs). Moreover, a field monitoring of soil water content was carried out by multi-profile soil moisture sensors, allowing the assessment of the hydrological response of the soil covering and of the regime of groundwater recharge process as well. Among the principal outcomes, for each land cover class, changes were observed in the values of the depth at which the evapotranspiration effect is extended and in the Available Soil Water Depth (ASWD). Based on a consistent spatial modeling of soil thickness and soil hydrologic properties, the Soil Water Balance code (SWB 1.2) was applied to evaluate the spatial and temporal variability of the groundwater recharge in the karst aquifer. As a principal outcome, groundwater recharge rates were found to be dependent on land cover class and soil thickness as well, showing lower values for wooded areas and higher for denudated ones, respectively due to the higher and lower evapotranspiration rates. The presented methodology allows the advance of the knowledge on hydrological processes controlling groundwater recharge in karst aquifers, thus strengthening the basis for the improved of water resources planning.

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Interdisciplinary characterization of karst aquifer of the island of Vis (Croatia)

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Abstract

Vis is a small and remote island in the eastern Adriatic Sea and is mostly composed of karstified carbonate rocks. The island belongs to the Dinaric karst region and it exhibits peculiar geological and hydrogeological settings resulting in the autonomous water supply from island karst aquifer. The main water supply site, the Korita well field, is in the central part of the island, where it is protected from seawater intrusions by two low permeable hydrogeological barriers: (i) the volcanic-sedimentary-evaporite complex (i.e., diapir structure) from the W, and (ii) the karstified rock mass infilled by clay sediments below the *poljes* from the S. The current pumping capacity (maximum of 42 l/s) meets the demand most of the time. However, intensive summer tourism and climate change exert high stress on groundwater resources during the dry season. Consequently, in the last decade, occasional reductions for consumers occurred. Over the last two decades, systematic and interdisciplinary research was undertaken to protect this excellent karst aquifer and to provide a basis for the sustainable utilization in the face of changing climate. In particular, detailed aquifer and catchment characterization was performed by combining hydrogeological (pumping test, tracer test, periodical and continuous monitoring of GW level, electrical conductivity and temperature), hydrochemical (ion and isotope compositions of the groundwater), geophysical (electrical resistivity tomography and magnetotellurics), structural (geometrical attributes of faults and fractures), and hydrological (water balance calculations and climate modeling) methods, including the socio-economic analyses (projection of future water demand). Thus far, the results evidenced that the island's groundwater resources exhibit long-term stability in terms of quality and quantity despite the high variance in the precipitation (sole source of recharge), indicating relatively large groundwater reserves with a good resilience towards seasonal peak pumping rates and periodical droughts. However, rising anthropic pressure in terms of increasing water demand, coupled with the projected climate change and potential seawater intrusion could aggravate the quality and quantity of island's groundwater resources. Hence, the main purpose of the ongoing and future research is to provide a composite solution for achieving sustainable water supply by combining approaches based on (i) new perspective zones and new water supply wells, (ii) early warning system for seawater intrusion, (iii) increase of pumping rates at the Korita well field, (iv) revitalization of rainwater harvesting systems for agricultural irrigation, (v) managed aquifer recharge, and/or (vi) small desalination plant.

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Keywords: island karst aquifer, multidisciplinary hydrogeological characterization, sustainable water supply, climate change

Interpretation of cumulative frequency distribution curves of groundwater levels can bring information about the hydrodynamic properties of a karstified aquifer

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Abstract

Using statistical methods, Erguy et al. 2023 developed new approaches to gain knowledge about the hydrodynamic behaviour of karst aquifers using water level measurements in boreholes. They thus provide a table interpretation of cumulative frequency distribution curves of groundwater levels on the scale of the rainfall event, to extract the hydrodynamic properties of the aquifer.
They used data from the Cadarache site of the French Alternative Energies and Atomic Energy Commission (CEA) in south-eastern France, which is subject to rapid groundwater floods. The site is particularly well-instrumented, with 115 boreholes equipped to measure high-time frequency water levels for up to 15 years.

Using water levels' cumulative frequency curves, and thanks to the density of instrumented piezometers on this site, they could make clustering of boreholes behaviours. Four principal configurations were exemplified when the borehole crosses the heterogeneities of the aquifer. For example, depending on the water levels' cumulative frequency curves breaking slope, differences between the permeability of two zones in a borehole can be highlighted. Water losses to a very transmissive section or the presence of a very low permeability zone can also be determined. Their results were in concordance with the geological structure of the reservoir and observations from some cores.

The method presented is simple and can be applied to bring valuable information about the geological structure of the aquifer. However, it is valid only at the borehole location and it was not tested at other study sites.

To explore the potential of the analysis grid on other aquifers, we simulated hypothetical

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heterogeneous aquifers using a computer program for simulating groundwater flow in porous media. The four configurations were tested: (a) the borehole crosses a non-permeable layer above a permeable layer; (b) the borehole crosses a very transmissive zone above an intermediate permeable zone; (c) the borehole crosses a more permeable layer above a less permeable layer; (d) the borehole ends in a very low permeable layer trapping water which need an important rainfall event to connect the borehole to the rest of the aquifer. Applied to karst, the low-permeability zones can correspond to massive non-fractured limestone, the intermediate permeability layers to fractured and more or less connected zones, and finally, the highly transmissive zones may be associated with the presence of conduits or epikarst.

An increasing water level was applied in each borehole and the water levels' cumulative frequency curves were computed. The results obtained with the model were compared to Erguy et al. 2023 interpretation table to check if the method would be valid at other locations than the site where it was developed. The implemented method can not be applied to discharge hydrographs.

Erguy, M., Morilhat, S., Artigue, G. *et al.* A new simple statistical method for the unsupervised clustering of the hydrodynamic behavior at different boreholes: analysis of the obtained clusters in relation to geological knowledge. *Environ Earth Sci* **82**, 451 (2023). https://doi.org/10.1007/s12665-023-11066-z

Karstic conduit dimensions : Analysis and simulation

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Abstract

Karstic environments are characterized by large networks of conduits that strongly impact the groundwater flows. Often, when considering explicitly the karstic drains in flow modelling or forecasting, the conduit dimensions are assumed to be constant on karst branches or even on the whole network. All speleologists witness, however, the large variations of conduit dimensions and shapes, even in a single conduit.

In this work, we first present the results of a statistical analysis of the karstic dimensions that we have done on a set of 49 natural karstic networks. To do so, the karstic networks are converted into a mathematical graph with properties describing the conduit geometry: the equivalent radius and the width-height ratio. The median value for the network set is 1.22 m for the median equivalent radius (minimal median values around 0.5 m and maximal median values around 4.8 m), and 1.00 for the median width-height ratio (minimal median values around 0.2 and maximal median values around 2.1). The results do not allow us to identify any generic statistical law, nor hierarchical organization of the conduits. The development of an original 1D-curvilinear variogram permits, however, to characterize the spatial variability of these properties. When the networks have enough nodes to permit a robust analysis (> 100), a curvilinear spatial correlation is observed for small distances, that can generally be modelled with an exponential variogram. For both studied properties, variogram ranges vary from 50 to 500 m (median around 150 m) and show a nugget effect partly due to the sampling process (average spacing between two points of around 7.5 m). A study distinguishing the network branches demonstrates that the variability is smaller inside a branch than between different branches.

Second, we present two methods to stochastically simulate karstic conduit dimensions. The first one is based on the Sequential Gaussian Simulation method. It is declined at two scales: the total network scale and the conduit scale. The second approach we have tested is based on multiple-point statistics (MPS). The originality of both SGS- and MPS-based methods is to be developed and applied outside the classical frame of a 2D or 3D variable with spatial coordinates. Karstic systems are, indeed, represented as graphs and distances between points are curvilinear ones. The MPS method is based on the Direct Sampling algorithm (DS) and

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is adapted to the underlying graph structure.

The application of the proposed methods on natural networks demonstrates their capacity to simulate geologically-realistic karstic conduit dimensions, which could now be used to better assess the uncertainties in underground flow simulations. From a larger point of view, this work paves the way to property simulation on graph structures.

Long term discharge analysis to improve knowledge about the behavior of karst spring under climate change – Praondè spring, Civate (LC).

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Abstract

Climate change can significantly impact on water resource, in terms of quality and quantity. In a changing world the climate can intensify the vulnerability of hydrogeological systems such as karst aquifers. The combination of long dry summers with the change in the trend of precipitation (characterized by few but very intense events) is expected to influence the storage of water that could intensely decrease with important consequences on potable water in mountain area. Also, quality of water may change: water turbidity and water pollutant can increase. The aim of this work is to better understand the behavior of a karst spring (Praondè) located in the province of Lecco, in the town of Civate. The purpose is to identify possible models of spring behavior for a better management of water resource. In the beginning, precipitation and temperature data, extrapolated from ARPA Lombardia, were analyzed to identify a specific climate trend in this area. Then, thanks to the collaboration with Lario Reti Holding S.p.A, discharge data of the spring were analyzed. Since November 2023 discharge data were paired with electro conductivity and temperature of the spring, thanks to the installation of a multiparameter probe. Since January 2024, an automatic sampler has been installed to collect a sample of water every day (24 days) to obtain a continuous isotopic series of oxygen and deuterium. To describe the behavior of the spring, several parameters were detected. These parameters provide us information on how aquifer in being drained and the level of vulnerability of the spring. The most important parameter detected is the depletion coefficient α (Maillet, 1905). The outcome of this analysis is important for predicting possible behavior of the spring in different extreme climatic conditions. The hope is that this work will help in the future for better water management to make up for the increasingly frequent drought periods that affect several areas of the world.

Keywords: Vulnerability, karst, Hydrograph, Climate change

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Performance and intercomparison of two hydrogeological models (semi-physical and neural networks) to forecast groundwater floods of a fractured karst aquifer. Case study of the Cadarache site of the French Alternative Energies and Atomic Energy center (southeast France)

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Abstract

Floods are a hazard capable of causing major damages, hence forecasting them constitutes an important area of research. Floods related to surface water are well known and closely monitored, but the study of groundwater, which can partially or entirely contribute to floods, especially in karstic environments, is less developed. The Cadarache site of the French Alternative Energies and Atomic Energy center is prone to these groundwater floods. Following significant rainfall episodes, the level of the fractured karst aquifer can rise locally by more than 30 meters leading to overflow, artesianism and pressure on underground structures.

This paper aims to conduct a comparative analysis between two distinct forecasting models within the scope of this particular case study: i. pre-existing semi-physical reservoir model and ii. artificial neural networks model.

The performance of these two types of daily models with a 24-hour forecast horizon is compared and discussed in consideration of their operational use on the site. Both models use daily databases. The first model aims to reconstitute the groundwater levels based on meteorological data (rainfall, temperature), piezometric data (initial level, minimum level) and the calculation of various parameters (ETP, ETR, infiltration, storage) by calibrating various measurable and non-measurable parameters. This pre-existing model is currently used

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at the Cadarache site for forecasting karst floods. The second model is an artificial neural network model of the multilayer perceptron type using rainfall, temperature and piezometric data for forecasting groundwater levels.

These two models were compared on past measured meteorological data. The hydrogeological year 2019-2020 was chosen for comparison as it contains the flood episode of October-November 2019. This episode stands out as one of the most important recorded events on the site. It contains several successive rain events, the most significant being the first one in October with 185 mm in four days and the second in November with 100 mm in three days. Different quality criteria used for flood forecasting are compared (persistency criterion, SPPD ...), as well as the number of false positives/negatives of each model for exceeding a critical water level for crisis management. Comparing the overall performances of each of the models using, for example the Nash-Sutcliffe model efficiency coefficient, the neural network model appears to be more efficient than the semi-physical model with respective coefficients exceeding 0.8 for the former and of 0.6 for the latter. In particular, the neural network model provides a much better simulation of the aquifer recession phase. However, the physically based model has the advantage of not requiring previous levels measured directly prior to forecasting. This serves as a considerable benefit in cases where the automatic sensors installed in the piezometer are no longer functioning. Thus, from an operational point of view, these two models are complementary.

Keywords: Karst, Neural Network, Artificial Intelligence, Model, Flood, Forecasting, Groundwater

Possible effect of deep CO2 degassing in the formation and development of karst systems

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Abstract

Recent studies have shown the existence of two large structures of deep CO2 degassing in central Italy
(Chiodini et al., 2004). In this contribution, the investigation and some preliminary results on the possible
impact of such degassing on the development of karst systems in these areas are presented. Authors
propose the term Deep Carbon Enhanced Karst System (DCEKS) to identify an extensive karst system
where the contribution of CO2 of deep origin may have enhanced its development. The action of H2S on
carbonate rocks also generates impressive karst system; such caves are well known and described in the
literature, but according to our interpretation, the morphologies generated by H2S are different from those of
DCEKS. In order to understand the possible effect of deep CO2 , the typical morphologies developed in the
caves of the Lepini Mts., one of the areas presenting deep CO2 high degassing rate, have been analyzed. In
the vadose zone, two different types of morphologies have been identified: the first is shaped by infiltrating
water and the second by flowing water. Examples of these two different types of cave morphologies can be
found in the initial sector of the "Abisso Consolini" and at the "Ouso di Pozzo Comune" caves.
The first type of caves develops in areas with a very limited or non-existent superficial drainage where the
water rapidly infiltrates into the ground; the caves are therefore characterized by chimney-like vertical

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morphologies with height around fifty metres or more. Such type of morphologies corresponds to the "inverse
erosion" theory, proposed by Maucci in 1975.
Regarding the second type, flowing water shapes the rocks with typical meandering structures interrupted by
vertical pits of lower depth (few tens of metres). These caves are constantly interested by flow of water,
except during periods of prolonged drought.
In this contribution, authors suggest that the extensive development of chimney-like features in the Lepini
Mts. may have been enhanced by deep CO2.
The development of caves in the phreatic zone is generally difficult to study due to the presence of flooded
passages. The "Inghiottitoio del Merro" in the Cornicolani area is a vertical pit, first explored by speleodivers
and then by underwater ROVs down to 450 m (around 300 m b.s.l.). In line with what has been proposed by
Baiocchi et al. (2018), the morphologies in the cave can also be explained by the effect of deep origin CO2
creating a DCEKS in the phreatic zone. Although our investigation is still in progress and at a preliminary
stage, it suggests the possible key role of deep-origin CO2 in the speleogenetic process.

Keywords: Hypogenic Cave, CO2 Degassing

Post-Devonian fault and fracture systems and their impact on karst and groundwater flow in the Carboniferous limestones of Ireland.

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Abstract

It is not often high quality rock exposure is available over a wide area so that consistent models for the impacts of different faults and fracture systems on karst and groundwater flow can be defined. Within the Lower Carboniferous limestone and shale sequences of Ireland, this is the case. Quantitative analysis of high quality, quarry, mine and outcrop exposure was assessed over much of the Irish midlands in order to assess structural controls on groundwater flow. It was found that the conditions affecting the rocks during and post deformation have a fundamental impact on how the different faults and fractures impact groundwater flow today. For instance, due to their formation or post-formation lithostatic (burial) and tectonic loading, Lower Carboniferous normal faults and Variscan veins and faults are intrinsically sealed to groundwater flow. Later uplift of the same rocks has meant the formation of later structures that are intrinsically open, with the main ones identified as Cenozoic strike-slip faults and stress release joints.

A natural outcome of this analysis is the characterisation of the impact of the different faults and fractures on the location and geometries of surface and subsurface karst. For instance, apertures of intrinsically open fractures are more likely to be affected by solutional enhancement along their entire plane while intrinsically sealed fractures are more likely to be less persistently karstified, with fractures remaining partly sealed. In the mines, particularly Navan mine, the impersistent karst on some of the Lower Carboniferous normal faults has been characterised as resulting from where the NE oriented faults have been intercepted by later intrinsically conductive NW oriented Cenozoic strike-slip faults. This process of is considered to have been important for the formation of isolated depressions along regional scale Lower Carboniferous normal faults in central Ireland as identified on a gravity anomaly map of Ireland.

Variscan veins are also intrinsically sealed, it can appear however that karst is intimately localised along the fracture plane. Analysis of many Variscan veins from quarry exposure finds that micrometre to millimetre scale apertures occur along most veins, particularly larger ones (> 1m height). The discrete and persistent nature of this aperture along the veins suggests that it must have involved conductive fracturing. There is a good possibility therefore that the inception of caves along Variscan veins in the classic karst region of the Burren in the western part of Ireland can only have occurred due to the involvement of conductive fracturing. Steep Variscan veins in limestone rocks uplifted towards today's surface are likely

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to have first allowed surface water along the veins when affected by conductive fractures. Further evidence of the role of conductive fracturing in localising karst is the ubiquitous grikes along veins and stress release joints on the exposed limestone surface of the Burren. The most likely explanation for the inception of this dissolution is that surface water has exploited the conductive fractures that have intercepted the bedrock surface, whereupon the surface water is conveyed below the surface.

Keywords: Faults, fractures, groundwater flow, karstified apertures, pathways, subsurface

Project MIKAS (Most Important Karst Aquifers' Springs) – achievements since EUROKARST 2022

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Abstract

The aim of the MIKAS (Most Important Karst Aquifer's Springs) project is to create the first complete list of the most important karst springs at the global, but also at the national level. The project was launched at the annual meeting of the Karst Commission (KC) of the International Association of Hydrogeologists (IAH) in June 2022, during the last EUROKARST conference held in Malaga. The MIKAS project's Advisory Board consists of one representative from each continent who work together with three rotating chairs of the KC, and the project team leader - the first author of this abstract. All of them are members of the KC, which is one of the most active IAH groups, with a tradition longer than 50 years. The UNESCO-IHP provides project monitoring and will sponsor some of the activities.

Why karst springs should be prioritized in creation of global catalogue of springs? Karst covers more than 15% of the continental ice-free land, while karst aquifers supply potable water to approximately 9.2% of the world's population, i.e. some 700 million people in 150 countries. The springs emerging from karst aquifers are globally the largest – some are even discharging entire underground rivers. They are also supplying potable water to many large cities with several million inhabitants, such as Rome, Vienna, Naples, San Antonio and Damascus. They are significant because they provide precious high quality water, sustain ecosystems, and maintain the baseflow of many of the world's rivers. The intakes of springs are the most common tapping structures in karst environments, because channelling gravity springs and diverting water even over long distances is much easier than drilling numerous wells in hard, dominantly carbonate rocks.

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Since the beginning of the project, the Advisory Board (AB) completed the Guidelines which include selection criteria for the two established groups, MIKAS (the list of globally important springs) and NIKAS (nationally important springs), as well as the Spring's Survey Form.

The selection criteria are the following: historic, aesthetic, economic, scientific and ecological. The MIKAS and NIKAS lists should be created based on these common criteria, but should also be adapted to local conditions, recognising the specific circumstances of each country. Something that is important in one country does not have to be important in others.

As of December 2023, the MIKAS project involves 103 national experts who have agreed to voluntarily work on the project. Their expertise has so far helped evaluate more than 100 springs in 22 countries, and at the end of the process these experts will have covered 99 countries from all the continents. Some countries and regions such as Central Asia or the Caribbean are still lacking experts, but we expect the promotion of the project's achievements to increase the number of "karst countries" and complete the list of experts. More information about the project, including the Guidelines, the Survey Form with required data and the list of engaged experts, can be found at: https://karst.iah.org/projects.

Keywords: karst springs global national MIKAS

Regional-scale groundwater modeling, focusing on boundary inflow and impact assessment of managed aquifer recharge in karst systems

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Abstract

Water scarcity is a significant problem in many parts of the world. To address this issue, Managed Aquifer Recharge (MAR) strategies are crucial in mitigating the adverse impacts of overexploited groundwater resources and enhancing groundwater availability. In regions with water scarcity, like Lebanon, there's a growing need to employ existing MAR techniques for storing water or increasing subsurface flow from upland karst systems into nearby alluvial aquifers. However, implementing MAR in karst systems is particularly challenging due to their extreme hydraulic anisotropy, heterogeneity, and high runoff dynamics.

Distributed numerical groundwater models that incorporate discrete-continuum approaches, such as MODFLOW-CFP, coupled with stochastic generation of karst conduit networks and idealized model setups, enable the quantification of alluvial karst interactions and the comparison of MAR scenarios. A script-based framework was developed entirely built on open-source tools, offering a scalable, automated, and generalizable workflow for a multi-model approach. It includes automatic calibration via parameter estimation software PEST, comprehensive preprocessing and postprocessing. The framework integrates various Python packages, specifically FloPy, CFPy, pyKasso, and provides a linkage to geographic information systems (GIS), to systematically create a multi-model concept that considers diverse karst conduit network realizations within MODFLOW-CFP models. This enables the quantification of boundary inflow and facilitates MAR assessment. Postprocessing routines provide insights into error analysis, local and global water budgets, network probability, parameter uncertainty and sensitivity.

In a first idealized scenario, focusing on a regional-scale karst-alluvial multi-model for the Nabaa El Berdaouni spring in Lebanon, the established modeling framework was evaluated for a real system. The model effectively replicates observed data (monthly spring discharge). However, it suggests limited suitability for different injection and infiltration scenarios at a potential MAR location within the region. The results also emphasize the importance of critically assessing and acknowledging uncertainties in model outcomes, primarily due to limited initial data.

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[*]Speaker

Simulation of the polyphasic karst system of the Barrois limestones with a discrete karst network simulation method

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Abstract

The Barrois region corresponds to a Tithonian-age limestone plateau located to the east of the Paris Basin, and constituting the most karstified area in the basin. This limestone is primarily exposed, except to the north of the plateau, where it is found under a semi-permeable Lower Cretaceous-age discordant cover where karstification is currently active. Karstification likely began during a phase of emersion of the summit of the carbonate reservoir (Jaillet, 2000) and has continued to the present day in various forms (ghost-rock karstification, hypogenic alteration, crypto-alteration, and epigenic alteration under cover) depending on the regional base level drop and the exposure of the Tithonian limestones through erosion of the Cretaceous cover.

In the past, an attempt to model this network was made in the context of surface pollution issues (Jaquet, 2004). Although this modeling was applied across the entire plateau, it was limited by a 2D modeling of the phreatic network along different horizons compartmentalizing the Barrois limestones, a purely epigenic karstification mechanism, and coarse drain resolution.

With the goal of better understanding the geometry of the karst network in the Barrois region to enhance the protection of the associated water resource, we propose to use the KarstNSim method (Gouy et al., 2023) to stochastically simulate various plausible 3D network skeletons within the Barrois limestones. This method allows constraining the network's

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morphology based on simple input parameters but also enables the replication of polygenic karsts through sequential simulations where each iteration influences subsequent ones.

Keywords: simulation, network, skeleton, stochasticity, polyphasic

Stream-centric methods for determining groundwater contributions and sources in karst mountain watersheds

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Abstract

Climate change influences on mountain hydrology are uncertain, but likely to be mediated through changes in subsurface hydrologic residence times and flowpaths. The heterogeneity of karst aquifers add complexity in assessing the resiliency of these water sources to perturbation, suggesting a clear need to quantify contributions from and losses to these aquifers. Here we develop a stream centric method that combines mass and flow balances to quantify net and gross gains and losses at different spatial scales for varied flow conditions. We extend these methods to differentiate between karst conduit and matrix contributions from the aquifer and to determine variability in springs and distributed groundwater contributions. In the Logan River watershed in Northern Utah we found significant amounts of the river water repeatedly gained and then lost through a 35 km study reach. The direction and amount of water exchanged varied over space, time, and discharge. Further, we established that springs and distributed groundwater inflow were similar and primarily from karst conduit sources. Streamflow was dominated by discharge of karst conduit groundwater after runoff with increasing, yet still small, fractions of matrix water later in the summer. These findings were combined with geologic information, prior subsurface dye tracing, and chemical sampling to provide additional lines of evidence that repeated groundwater exchanges are likely occurring and river flows are highly dependent on karst aquifer recharge and discharge. Given the large population dependent on karst aquifers throughout the world, there is a continued need to develop simple methods, like those presented here, for determining the resiliency of karst groundwater resources.

Keywords: groundwater, surface water interactions

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[*]Speaker

Strike-slip faults system and related karst networks: New insights from the comparison between deep buried karst in central Tarim Basin (NW China) and the Fontaine-de-Vaucluse karst system (SE France)

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Abstract

The Tarim Basin, with an area extent of approximately 560,000km2, is the largest intra-continental craton basin in China. It experienced a complicated poly-phase tectonic evolution from the Precambrian to Cenozoic. The tectonostratigraphic sequences of the central Tarim Basin are divided into several successions, separated by the regional unconformities. Hydrocarbon exploration in the central Tarim Basin, at the depth more than 6500m, have demonstrated that subsurface strike-slip faults exert essential influences on Ordovician karst-type carbonate reservoir distribution. Using high-quality 3D seismic data, geometric and kinematic characteristics of strike-slip faults consisting of both conjugate fault arrays and subparallel fault arrays in the central Tarim Basin are depicted with displacements in the order of hundreds of meters. However, due to the restriction of seismic resolution and the lack of sufficient drilling punctual samples, the relationship between lithology, distribution of strike-slip fault damage zones, and karst-type carbonate reservoir qualities is still highly uncertain.

Conversely, in the Fontaine-de-Vaucluse watershed (SE France), well-documented karst networks and strike-slip faults are directly accessible, raising the question of their genesis. This karst system is located in the north of the Provence fold-and-thrust belt, which forms the eastern limit of the Pyrenean orogenic system in southeastern France. Thanks to outcrops and karstic conduits exploration, complex geometries of the karsts system are highlighted sometimes or often with interactions with faults or faults corridor.

So, both the Vaucluse and central Tarim carbonate platforms have similar strike-slip faults and karst features, which comparative study can provide new insights to the understanding

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[*]Speaker

of the strike-slip fault controlled karst genesis.

Many structural features amongst which horizontal or sub-horizontal lineations on the faults/fractures surfaces are found both on outcrops and in cored wells to prove strike-slip faults affecting the Urgonian carbonate platform. Strike-slip faults and horizontal movements are also interpreted from the 3D seismic data from the Tarim Basin.

Also, in some outstanding outcrops close to Orgon, in the south-west of the Fontaine-de-Vaucluse catchment area, progradation of the Urgonian carbonate platform highlight the relations between lithology and distribution of fractures corridors and fault damage zones. These observations are completed using cored boreholes in the area by the analysis of the relation between lithology, faults and fracture densities, and karst occurrences. On the other hand, specific seismic attributes are used in 3D interpretation to characterize the damage zones.

The interest of such different means to characterize the relations of faults and karsts systems in these two carbonate platforms is the opportunity to interpret similar structural and diagenetic features from small-scale with core and thin-sections to basin-scale with 3D seismic interpretation. The objective is to define rules which could be applied at both scales and improve the understanding of the fluid movements and storage in this peculiar geological contexts.

Keywords: Tarim basin, Fontaine, de, Vaucluse, Strike, slip fault, Fault damage zone, Carbonate Karst

Temperature variations of karst springs

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Abstract

In most karst springs, water temperature is quite stable along the year, with a value close to the mean average temperature of the atmospheric air in the vicinity of the spring. However, some variations are observed, usually related to flood events, with an amplitude in the order of +-1∘C. A few authors (e.g. Luhmann et al., 2011, Luo et al., 2023) attempted to define categories of springs' thermographs and to provide conceptual interpretations.

The key question behind these variations is related to the thermal length or characteristic length of a water inrush into a karst system. The thermal length is the distance necessary for an input signal to reach equilibrium with the surrounding medium (e.g. Covington et al., 2012). For example, anyone can easily understand that a stream with a temperature of 18∘C swallowing into a ponor in a region with an average temperature of 10∘C may need several hundreds or even thousands of meters along its underground pathway to cool down to ˜10∘C and reach thermal equilibrium with the surrounding rock. It is also quite clear that rainwater infiltrating into the ground through soil and epikarst will equilibrate within a few meters, possibly a few tens of meters.

Besides the heat transported directly by water, at least three other processes are potentially controlling the water temperature of karst springs: 1) heat convection by air-flow through the karst massif, 2) heat conduction from ground surface or 3) heat conduction from the Earth depth.

Thermographs are thus controlled by one or several of these processes depending on conditions. An outlook on the range of possible situations is presented based on the existing literature and on preliminary numerical modelling, which couples these processes.

Case studies from various hydrogeological settings will be presented to illustrate the main parameters controlling spring temperature variations.

The understanding of all heat fluxes controlling underground temperature in karst regions is relevant not only for hydrogeology, but also for paleoclimatic reconstruction, geothermal exploitation and habitats (critical zone).

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Keywords: Karst springs, water temperature, heat exchanges, thermal length, numerical modelling

TERZAGHI'S EFFECTIVE STRESS PRINCIPLE AND HYDROLOGICAL DEFORMATION OF KARST AQUIFERS DETECTED BY GNSS MEASUREMENTS

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Abstract

Analyses of GNSS (Global Navigation Satellite Systems) data acquired by stations located in karst areas of the Apennine chain (Italy) have revealed a strong correlation between changes in water table levels and ground displacements in the horizontal plane. Many previous studies have applied a specific modelling approach to explain such a phenomenon, assuming that hydraulic head fluctuations due to aquifer recharge/discharge processes would cause the widening/closing of water-filled fractures subjected to continuous water pressure variations. These models, however, focuses exclusively on the effect of the variable hydraulic head in fractures, neglecting the role of the pore water pressure. In particular, a karst aquifer is triple porosity medium in which groundwater fills fractures, large voids and conduits, and pores and fissures of the rock matrix as well. Generally, wide water table oscillation characterizes karst aquifers of the Apennine. The low- and high-stand phases of the water table are associated with changes in the saturated zone thickness up to tens of meters, which lead to pore water pressure variations up to thousands of KPa at depth. The pore water pressure change affects primarily the saturated and epiphreatic zones and, thus, it modifies the state of stress of a wide rock volume. This study focuses on the hydrological deformational mechanism of karst massifs and provides the equations relating karst massif deformation to changes in the groundwater levels. A new physical explanation of this hydrological phenomenon was proposed by combining Terzaghi's effective stress principle with classical linear elasticity. In particular, Skempton's formulation of the effective stress was considered, which represents a generalization of Terzaghi's theory. The study highlights that the water pressure variation associated with the water table rising and lowering is the primary driver of the observed hydrological deformation. The proposed equations were derived assuming both unconstrained and constrained conditions of the karst aquifer. In the first case, the karst aquifer is free to expand laterally, and the hydrological strain depends on the overall elastic properties of the karst rock mass and the coefficient of earth pressure at-rest, $K0$. In the second case, an elastic aquitard laterally constrains the karst aquifer, and the strain induced by the change in pore water pressure also depends on the elastic properties and dimensions of the aquitard. The resulting strain is thus a fraction of the unconstrained hydrological strain. The karst aquifer hydrological deformation can be compared to the thermal expansion of solids, whose magnitude depends on the physical and geometric characteristics of the materials and the temperature increase. Similarly, the hydrological deformation is caused by a change in the pore water pressure, affecting the whole karst aquifer saturated zone. The ground displacements measured by GNSS stations at the surface depend on their location, as they are the result of the deformation accumulated across the aquifer.

[*]Speaker

The application of future climate scenarios to assess long-term effects of climate change on the discharge of the Caposele karst spring, Southern Italy

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Abstract

Global warming affects atmospheric and oceanic energy budgets, modifying the Earth's water cycle with consequent changes to precipitation pattern. The impacts of possible emissions scenarios on surface water have been widely investigated but the effects on groundwater discharge are still uncertain at a global and local scale. In order to assess future spring flow scenarios, the most critical step is to quantify the recharge-discharge connection.

The main aim of this research is to predict the long-term effects of climate change on the discharge of Caposele spring, an important spring primarily fed by Cervialto Massif, located in the karst system of Picentini Mountains, in the Southern Apennines (Italy). The Caposele spring, locally known with name of Sanità spring (422 m ASL), is unique for its exceptionally long series of discharge values, available for the timespan 1920-2023. The investigated spring, discharging out from limestone formations, is managed by the public water supply authority "Pugliese Aqueduct". Apennines stretch along the Italian peninsula in a Northwest-Southeast direction, crossing the Mediterranean area that represents a critical zone for climate change due to a decrease of recharge and increase of frequency and severity of droughts since the last two-three decades. Statistical tools have been applied to analyse both the time series of recharge-related parameters in the spring catchment, and the spring discharge time series.

The CMCC-CM global model was utilized, adopting its future climate scenarios projected over the Cervialto Massif. A multivariate statistical analysis was conducted to identify the correlation factors between historical spring's flow and historical meteorological parameters collected within the spring's catchment. Subsequently, these factors were applied to the previously chosen future climate scenarios. This process allowed for the estimation of future discharge of the Caposele karst spring.

The preliminary results have indicated that by 2040-2070 the average annual discharge of the Caposele spring could decrease by 8% or even 15% (depending on the selected climate scenarios) compared to that of the past few decades. The future water shortage in the Caposele spring would have an even more significant impact in a hydrogeological context already marked by water crisis: nowadays, the spring's discharge is much lower than that recorded in the 1920s or 1930s. By individually studying the time series of meteorological data, it becomes evident that the primary cause of the Caposele's discharge reduction is the dramatic rise in temperature observed in the spring's catchment (3.65 ∘C over 100 years of

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*Speaker

monitoring). The rising temperature has a negative impact on both liquid and solid precipitation. In fact, this leads to an increase in evapotranspiration, reducing the amount of rainfall that can infiltrate the aquifer and causing a double effect of shorter permanence of snow to the ground and a strong reduction of total snowfall over the Picentini Mountains.

Keywords: Karst spring, Groundwater discharge, Climate change, Discharge prediction, Regional climate model

The effect of the degassing process at Ferrarelle's karst hydrogeological system.

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Abstract

Here we investigate the effect of the degassing process on Total Dissolved Inorganic Carbon (TDIC) isotopic composition (δ13CTDIC) in groundwater from the karst aquifer of *Ferrarelle's* hydrogeological system (HFS, Riardo plain, Southern Italy). HFS is characterized by the presence of CO_2 supersaturated groundwater, whose partial pressure in the karst aquifer reaches at least 5 bar. Previous investigations indicate that water-degassing processes cause a readjustment of the isotopic composition of the carbon species due to fractionation. Consequently, the δ13CTDIC of the water sampled at surface may be different than the original composition in the aquifer. The *Ferrarelle* wells field and the plant-setup for CO_2 extraction represent a perfect test-site for experimental investigation on δ13CTDIC evolution. This process has been investigated by sampling water and gas discharges at bell-shape gas separators, where also the discharge rate of water and the gaseous component ($CO_2 > 99\%$) are measured. The sampling has been carried out before (HW) and after (UB) the separator. In order to evaluate the potential water degassing effects on d13C throughout the sampling, the water solution has been collected both in the traditional 250 mL PE bottle and in a pre-evacuated glass flask equipped with a stopcock, where reactants for TDIC precipitation where previously added. Moreover, a dry gas sample has been also collected from the separator for δ13CCO2 analysis.

The carbon isotopic composition of TDIC shows a δ13CTDIC difference of ˷ 3‰ between the two different sampling methods. Sample UB after CO_2 loss shows a more positive δ13CTDIC value with respect to the HW glass flask sample. Applying an isotopic mass balance, considering the measured gas (fCO2) and water discharge (fW) rates, the analysed δ13CCO2 composition and the analysed δ13CTDIC(w) in water, we compute the δ13CTDIC composition of groundwater before degassing according to:

δ13CTDIC= ((fW) × δ13CTDIC(w) × TDIC + (fCO2) × δ13CCO2) / ((fW) × TDIC +(fCO2))

Results are consistent with a δ13CTDIC value of about +1‰ vs. PDB, the same value obtained on the HW glass flask. In addition, the carbon isotope input from $CaCO_3$ dissolution does not bias the total carbon isotopic composition, being the δ13CCaCO3 ˷1‰ in the Cretaceous limestone of HFS system, i.e. the same composition of the endogenous CO_2.

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[*]Speaker

Moreover, the flux of free CO2 measured at the bell-separator discharge is comparable with the theoretical degassed CO2 flux, computed by bringing back to equilibrium with respect to calcite the oversaturated water collected after the bell-separator. Consequently, also using the theoretical pre-degassed carbon composition it is possible to compute a d13CTDIC with a similar value of about +1‰.

Summing up, CO2 oversaturated groundwater might undergo degassing, inducing fast and significant δ13CTDIC re-equilibration, before or during the sampling. Special care must be taken when dealing with TDIC in these systems, because degassing processes can give biased results. If applicable, the methods of sampling via pre-evacuated glass flask could represent a reliable solution, otherwise a theoretical approach in reconstructing the composition of pre-degassed carbon speciation might be applied to obtain the original non-degassed TDIC composition.

Keywords: CO2 degassing, Karst aquifers, analytical tecniques, TDIC

The freshwater origin of a brackish submarine spring inferred from a long-term stable isotope survey: the Port-Miou karstic spring (SE France)

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Abstract

Coastal karst aquifers represent crucial water resources which are high vulnerable to sea-level rise, climate variability and anthropogenic influences. Understanding their vulnerability requires to identify their recharge area, aquifer characteristics and the mechanisms of seawater intrusion. The aim of this study is to define the origin of freshwater that feed a regional submarine karst spring, and give insight into the salinization mechanism. To this purpose, we propose an original approach based on a combined salinity and stable isotopes mass balances.
The submarine Port-Miou spring (S-E of France), represents a major regional discharge. Its situation is representative of the typical feature of Mediterranean coastal karsts developed at great depth below the current sea level. The catchment area has been evaluated around 400 km^2, from the sea up to 1148 m of elevation. It is located close to the Marseille city, where the freshwater demand is very high for drinking, irrigation and industrial supply. This submarine brackish spring discharges through a karst conduit explored by cave-divers, down to 237 meter deep below the sea level, 2 km inland from the seashore. This study is based on a long-term monitoring (over 10 years) of spring water water level (or discharge) salinity, and water isotopic composition (δ18O and δ2H). This survey is complemented by a database of regional groundwater and precipitation isotope compositions. At the Port-Miou spring site, the discharge may exceed 35 m3/s during flood events, but the salinity never falls under 2 p.s.u., making it continuously brackish.

First, a two-endmember mixing equation based on springwater salinity allows the source to be partitionned between continental freshwater and seawater. Second, the isotopic composition of the freshwater endmember is calculated using the seawater isotopic composition and mixing fraction. We discuss the time variations of the reconstructed freshwater isotopes composition with regards to the composition of regional aquifers and precipitation. During long summer recessions, the fresh isotopic signature moves toward a constant mean interannual value. It suggests the existence of a base flow, with an additional contribution of fast infiltration water during flood events characterized by more variable isotopic compositions.

Keywords: costal karst, costal spring, stable water isotopic data, long term survey, mixing equation

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The hydrodynamic response of the Sibillini Mts. carbonate hydrostructure before and after the Mw 6.5 Norcia earthquake (Central Italy): hints from numerical models

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Abstract

Apennine carbonate hydrostructures host important aquifers, leading to the storage of extensive amounts of groundwater and representing an important water resource for the Italian peninsula. The hydraulic properties of aquifers vary based on lithological heterogeneity, fracturing, and karst conduit development. Accordingly, the groundwater flow is further controlled by tectonic and structural elements.

During the 2016 Central Italy seismic sequence, the Mw 6.5 Norcia earthquake caused significant, long-lasting hydrogeological changes in the Sibillini Mts. carbonate hydrostructure. The seismic event, originating from the rupture of different segments of the Vettore-Bove normal fault system, resulted in important ground deformation with surface faulting. The mechanism of "aquifer fault rupture" (Mastrorillo *et al.*, 2020) has been invoked to explain the sustained discharge changes observed at springs and along the main drainage systems, suggesting a shift of the groundwater divide following the Vettore fault rupture. In this work, we aim to characterize the Sibillini hydrostructure and assess the hydrodynamic response to the coseismic dislocation of the Vettore fault by means of numerical approaches.

Following the concept of parsimony, we constructed a straightforward model representing the earthquake-related hydrodynamic changes of the Sibillini carbonate hydrostructure. We idealized the model as a simplified hydraulic system consisting of three volumes separated by faults (Vettore and Norcia faults). Given the regional-scale extent of the model, we assumed the Sibillini carbonate aquifer as an equivalent continuous and homogeneous medium, with an average permeability for the entire area. We implemented faults in the model (Vettore and Norcia faults) as horizontal flow barriers with different permeabilities than those of the aquifer. First, we simulate the groundwater flow before and after the Norcia earthquake. Then, we performed an automatic calibration of the model using observed spring discharge and hydraulic head data as target function. The modeling allowed us to define the hydraulic parameters characterizing the hydrogeological system at a regional scale. Groundwater modeling results are compared with the crustal volumetric changes obtained from the simulation

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of the Vettore fault rupture through a geomechanical numerical model. The comparison will contribute to enhancing the groundwater model by evaluating and refining permeability variations within the system, especially in post-seismic conditions.

The role of groundwater-surface water relations in disturbing lake ecosystems: the case of the Rémoray Lake Natural Reserve (Jura, France)

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Abstract

The Lac de Remoray National Natural Reserve was created in 1980. Its purpose is to conserve biodiversity and maintain the state of the natural environment. A wealth of biological diversity is found in the wetlands around Lac de Remoray. The trophic and acidity gradients result in a high mesological diversity and, consequently, a large number of remarkable or protected species. Conservation management is now implemented using three tools: no intervention, extensive grazing, and late mowing. Despite this management approach, the lake's water quality has deteriorated in recent years. One of the findings is that the proliferation of decomposers is suffocating Lake Remoray. This is linked to the excess of organic matter and nitrogen from the agricultural land in the catchment area. Studies have been carried out to identify the origin of these transfers. These have focused on the main tributaries of the lake, without taking into account the geological context of the area and the contribution of groundwater to the contamination. From a more general point of view, there is currently no definition of the hydro-geological basin of Lake Remoray. However, the lake is in a karstic context, which implies that there are numerous underground circulation systems, which allow the communication of sometimes distant hydrographic networks. Knowledge of the hydrogeological boundaries should allow other, more distant sources of pollution to be taken into account. This study aims to assess the potential for groundwater transfer from a small catchment located to the west of the catchment and separated from it by a regional fault (the Mouthe Fault). The Mouthe Fault is considered to be a barrier to water transfer. To propose a new delimitation of the hydrogeological basin of Lake Remoray, this work proposes a multidisciplinary approach to the characterization of flows. For this purpose, all water bodies (surface water and groundwater) have been mapped and then characterized through hydrological balances at two scales: topographic basin and hydrogeological basin. These balances indicate the presence of inputs from outside the topographic basin as well as exchanges between the different systems. This is consistent with the karst context of the study area. The hydrological behavior of the lake's two main tributaries (the Drésine and the Lhaut) also varies according to the hydrological regime, as shown by the flowmeter study carried out at high and low water levels. Similarly, the study of geological structures is an indication of the fact that certain connections are only possible during periods of high

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water. Finally, the characterization of the physicochemical signatures of the groundwater has revealed three characteristic signatures of the Cretaceous and Jurassic aquifers. The Jurassic signature influences the Cretaceous signature. Finally, a joint study of the flow rates, the structural arrangements (geology), and the physico-chemical characteristics of these waters has identified a contribution coming from the closed basin to the west of the Mouthe fault. This link will be subject to verification using artificial tracing.

Tracer dispersion in karst conduits: study of spatially heterogeneous breakthrough curves by multi-point dye tracing and 3D Computational Fluid Dynamics (CFD) simulations

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Abstract

Dye tracing techniques are extensively used in karst systems. It is either used as a qualitative approach, such as establishing connections between losing streams and resurgences, or in a more quantitative way, by estimating travel times, maximum and modal velocities, conduits dimensions, longitudinal dispersion, retardation effects, etc. However, studies suggest that tracer breakthrough curves (BTCs) can be significantly heterogeneous across a karst conduit transversal section, and thus allowing for misinterpretation of some critical parameters. This paper attempts to quantify BTC variations across a karst river profile and explain them by various hydrodynamic features. The goal would be to highlight the risk of misinterpretation of tracer tests results in case of an inadequate placement of the fluorometer for which the BTC could be non-representative of the main hydrodynamic behavior of the underground river. The methodology used is composed of two main approaches: (i) field tracer tests campaigns using transversal multi-point configuration, implying the use of multiple fluorometers (up to 15) placed across a river section; (ii) solute transport models, specifically implying the use of 3D Computational Fluid Dynamics (CFD). The results from multiple profiles in different caves are presented, for which both observed and simulated BTCs are shown. The observed heterogeneities can be significant and various. The CFD models give consistent results with the field observations and can be used to visualize in 3D the hydrodynamic behaviors responsible for these heterogeneities. The discussions include the significant effects of a reverse flow zone (due to an Eddy current); the mixing length, after which the lateral dispersion is supposed enough to imply a satisfactory distribution of solute across the section; the effects of an upstream convergence of two tracer clouds; the link with the velocity profile; etc. The conclusions indicate that significant heterogeneities can be observed across a karst river profile, and thus that the position of the fluorometer can induce a significant misinterpretation of tracer tests results.

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Keywords: dye tracing, karst, numerical modelling, solute transport, CFD

Transitory hydrodynamic state as a tool for inferring geometric constraints on groundwater flow in karst aquifers

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Abstract

A comprehensive understanding of recharge mechanisms, flow movement, and the hydrogeological functioning are needed to properly manage water resources from carbonate aquifers, particularly for human consumption. Karstification implies the appearance of elements that favor flow dynamics (conduits and preferential flow paths), but also others that hamper groundwater flows or increase tortuosity of a specific drainage route (siphonage structures, thresholds, among others). In addition, recharge events characteristics (rainfall intensity, total amount, etc.) can also affect to the hydrodynamic regime of the system.

In this research, a quantitative analysis of the transitory hydrodynamic state, by jointly monitoring the inflow –recharge- and outflow –discharge- volumes, has been applied for detecting geometrical constraints affecting groundwater flows within a binary karst aquifer located southern Spain (Sierra de Ubrique, Cádiz province). Daily data set concerning the global system recharge and discharge, collected during five hydrological years (2013/14 – 2017/18), was used in this work. A significant fraction of the recharge takes place through swallowholes (concentrated recharge) that collect runoff water from small basins of impervious materials. Discharge occurs through two permanent outlets (Cornicabra, 349 m a.s.l., and Algarrobal, 317 m a.s.l.), in addition to an overflow spring (Garciago, 422 m a.s.l.). With 26 km2 approximately this aquifer is the main source of water for approximately 16000 inhabitants of Ubrique city.

The results show that the hydrodynamic response of the main springs is driven by the relationship between the accumulated recharge and the total discharge of the system. The value of the daily difference (in hm^3) between cumulative data series (recharge and discharge), defines the aquifer transient water volume stored into the aquifer. Thus, each recharge episode triggers a hydrodynamic response in the Cornicabra, with no response in the other springs. It is necessary a transient stored volume into the aquifer of approximately 3.2 hm3 to trigger changes in Algarrobal and Garciago springs. These volumes would be related to the existence of geometric thresholds that determine the hydrodynamic response in the Algarrobal and Garciago outlets. In addition, the analysis of the slopes defined by the linear relationships between the hydrodynamic state and the discharged flows provide additional information on the karstification development in the aquifer sectors drained by each spring. However, it is often difficult to establish properly the hydrodynamic state of the aquifer due to 1) the uncertainty related to the recharge estimation approaches (commonly empirical methods), both temporal and spatial distributions, and 2) the hydrometric monitoring inaccuracies found in the outlets. Sensitivity analysis of the equations for estimating potential

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evapotranspiration (the main parameter driving the recharge rate) and the continuous monitoring of the drainage can further enhance the calculations representativeness.

Continuous monitoring of recharge and recharge parameters is shown to be a useful methodology for inferring the presence of geometric constraints to discharge flowing and can be a reliable tool which can support the management of water quality impacts related to high water events.

Keywords: Recharge, Discharge, Threshold, Hydrodinamic response

Trends in long-term hydrogeological data from European karst aquifers

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Abstract

The impact of global change on water resources is mostly associated with changes in hydrological extremes, whereas the future evolution of groundwater recharge is currently highly uncertain. Due to short response times of karst systems, they might be used to get a better understanding of the impact of climate change on groundwater resources. This work aims at depicting a continental overview of changes in groundwater resources in karst areas over the past decades, based on more than 50 springs spatially distributed over Europe. One of the expected results is to illustrate in what way local information may help to understand regional changes. Observational data (Air temperature, Precipitations, Spring discharge) from karst areas were analysed for two different periods. The first period focuses on European springs with the longest available time series (~40 years) and the second one covers the last two decades. For discharge, changes were analysed using a combination of Mann-Kendall test for monthly spring discharge and annual extremes, expressed by different quantiles. Trends are also computed on monthly precipitation and temperature to identify changes in the input signal. In order to reveal the impact of groundwater dynamics on observed trends, two specific indices related to storativity (baseflow index) and inertia (memory effect) were calculated for the two periods. Over the last 40 years, results showed that as expected air temperature increases at all recharge area of European springs, but trends in precipitation are almost absent except only small areas. Only roughly 25% of the analysed springs exhibit significant changes in discharge. Negative vs. Positive changes in discharge trends reflect a South-North separation. Analysing trends in observational hydroclimatic and hydrological variables over the last 20 years provide a continental insight into these changes covering a wide range of hydraulic properties, climates, and topographies. Differences in discharge distribution are analysed as a direct consequence of structural differences of the systems, here considered by using the two indices related to the storativity and inertia. In combination, these indices were able to i) highlight structural differences and ii) characterize karst systems accordingly. From our results, outlooks on the key processes controlling changes and patterns are discussed.

Keywords: Climate change, trend, global scale, groundwater resource, recharge

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Understanding climate and anthropic drivers of discharge decline of a large karstic spring feeding a NATURA2000 ecosystem

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Abstract

The Ninfa Spring (Central Italy) supports a unique ecosystem, recognized as a NATURA2000 site and currently managed by the Fondazione Roffredo Caetani (https://frcaetani.it/). The site is visited by hundreds of thousands of visitors a year from all over the world and its economic importance is significant for the local communities.
The complex nature of the Lepini Mountains aquifer system, feeding several springs at the foot of the carbonate ridge, has been extensively documented in recent studies. The role of spring flow in sustaining local ecosystems and as a source of irrigation water in the foothill plain is well known, and the observed discharge decline jeopardizes the survival of environmental and economic activities.

In this contribution, we present an ongoing project, focused on the conceptual modelling of groundwater flow in the North-Western side of the carbonate structure of the Lepini Mountains feeding the Ninfa Spring. This research aims to construct a conceptual model of the Ninfa Spring translated into a preliminary transient flow model designed for hypothesis testing. Specifically, we aim to verify the relative importance of the groundwater withdrawals from the carbonate aquifer both upgradient and downgradient of the spring, and the decreasing recharge due to climate change, on the spring discharge which is now appreciably lower than in the past. This understanding is essential for any future efforts to protect the spring ecosystem and to properly address the monitoring activities. The mechanism of interaction between the aquifers and the ecosystem will be investigated as well as the time response of the spring system to long-term changes in infiltration rates, considering the relevant thickness of both the unsaturated and saturated zones in the Lepini Mountains. A special source of uncertainty is associated with this structure, hosting a flow system characterized by double porosity, with both a diffuse fracture network and developed karst conduits as evidenced by previous studies. How far this double regime affects the system's recharge and discharge will be investigated.
In a program of step-wise modelling, further data analysis and numerical modelling phases are designed to reduce the uncertainty associated with a quantitative assessment of the drivers influencing Ninfa Spring discharge depletion.

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Updating of traditional groundwater budget and recharge assessment by using the APLIS method at the karst Scirca spring (Central Italy)

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Abstract

Springs fed by carbonate and karst aquifers represent one of the most important sources of drinkable water in Central Italy and many areas of Europe, and there is a general recognition that their recharge–discharge equilibrium is at risk due to withdrawal increases and global climate change effects, especially in the Mediterranean area. Knowledge of the processes influencing springs discharge, and particularly the aquifer recharge distribution, is therefore of primary importance. Many studies deal with determining aquifers recharge by using conventional empirical methods starting, for example, from air temperature and precipitation data. However, these methods usually do not consider the peculiar hydrogeological features of the carbonate karst aquifers, which are characterised by heterogeneities (i.e., lithological boundaries and/or faults) and well-developed surface karst landforms, thus influencing the infiltration patterns. Furthermore, the conventional empirical techniques for determining the aquifer recharge are often challenging to apply, especially in mountainous regions where the necessary thermo-pluviometric information is scarce, and the calculation of the recharge spatial distribution is difficult. The APLIS method, which is gaining popularity as a substitute for traditional techniques to assess carbonate aquifer recharge and distribution, offers estimates at multiple scales, ranging from recharge areas of local springs up to the regional ones. Indeed, such a method allows to estimate the mean annual recharge in carbonate aquifers as a percentage of precipitation, based on altitude, slope, lithology, infiltration landform, and soil type.

Our research aims to estimate the recharge feeding the Scirca spring (Central Italy), which is of strategic importance for the water supply of about 50'000 people in the Umbria Region. The spring emerges on the western slope of the Cucco Mt. anticline, which is part of the Umbria-Marche Apennines chain. The core of the anticline is marked by the presence of a karst system among the most developed in Central Italy. The APLIS method was used to evaluate the aquifer recharge distribution along two observation periods: the first one

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(Period 1) ranges from 1959 to 2001. Previous studies for the evaluation of the water budget at an annual scale were conducted for this period, by means of traditional methods (i.e., Turc). The mean annual infiltration over the spring recharge area was evaluated in about 1000 mm/year. Results obtained by using the APLIS method on this period were compared with those determined by traditional methods and allowed to make it evident that the variable more influencing the recharge is the elevation.

The water budget was therefore estimated on a monthly scale, by using the Thornhwaite-Mather method, for a second period (Period 2), running from January 2010 to December 2022. Results were again compared with those obtained by using the APLIS method. The recharge amounts estimated by the two methods, in terms of percentage of rainfall, are comparable (about 60%). The use of the APLIS method made evident the need to redefine the recharge area based on a detailed geo-structural survey.

Keywords: recharge assessment, water budget, karst aquifers, Central Italy

TOPIC 1
Methods and models in karst hydrogeology
POSTERS

A corrosion-centric analysis of the chemical characteristics of low-saturated drips in Moravian Karst

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Abstract

Moravian Karst, the largest karst region in the Czech Republic, is built primarily from Devonian limestones and contains several cave systems with substantial speleothem formations. In search for causes of observed speleothem corrosion and destruction, low– or non–saturated drip/seepage water sources are often suspected causes. The presented study compares three such drips with distinctive properties.

Electrical conductivity (EC) and pH were measured on-site using multimeters (WTW or Greisinger). The saturation index with respect to calcite (SIcalcite) and CO2 partial pressure equivalent to carbonates in water (PCO2(W)) and the hypothetical PCO2 under which the water would be in equilibrium with calcite (PCO2(H)) are calculated via PHREEQC from carbonate alkalinity (acidimetric titration) and major ion concentrations (ICP-MS). All drips were sampled once or twice per month for at least 15 months.

The most aggressive water source (SI = –0.21±0.16), although with no observed corrosion features, is the seasonal drip M in Zemní Pyramids Dome in Amatérská Cave (Pracný et al. 2022) situated at a chimney opening ca 10 m above the floor. It shows significant seasonality (minima in winter, even becoming inactive; maxima in summer), relatively higher conductivity (403±49.6 μS/cm, seasonality as SI), and lower pH (7.45±0.22). The water shows a higher content of CO2 (logPCO2(w) = –2.37±0.29) than cave air and PCO2(H), suggesting limited water-limestone contact. The drip properties are most likely caused by rapid water transport from the surface into the cave.

The drip TC1 is a permanent drip in Tunelová Chodba in Punkva Caves. It is close to equilibrium with slight oversaturation (0.14±0.11), no seasonality, and low conductivity (297±22 μS/cm). It drips from a chimney edge with no visible corrosion features. The pH is relatively high (7.95±0.15), corresponding to the PCO2(W) and PCO2(H) being close to PCO2 in the cave atmosphere, indicating degassed water, which precipitated calcite. Therefore, prior calcite precipitation is the most probable cause of its properties (Pracný et al. 2016).

The last presented seepage water is BS1, a permanent shower drip along the cave wall in Pršavý Chimney (Býčí Skála Cave), notable for its wall-corrosion features. The drip shows high discharge and seasonal variability in pH (7.70±0.46) and saturation (0.05±0.42), with

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minima in summer and maxima in winter. Conductivity shows reversed seasonality and low values (286 ± 20 μS/cm). The seasonality, low carbonate saturation and overall mineralization suggest an unusual water flow path – the primary reservoir might be situated in a paleo-sinkhole filled with relatively non-reactive Mesozoic sandy sediments. An abandoned sand pit above the cave might represent an infiltration zone, from which the higher summer soil CO_2 is flushed into the dripwater's primary reservoir, leading to seasonally increased aggressivity.

A detailed long-term study shows the variability of low-saturated drips in properties and probable genesis. While some might result from a rapid influx of unsaturated water (drip M), others might form via seasonal effects due to unusual geological situations (drip BS1). Finally, some low-saturated waters might even result from calcite precipitation (drip TC1).

A hydrogeological observatory in southern Italy: The Foce experimental karst basin

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Abstract

Estimating groundwater recharge requires direct measurements, field data, monitoring, and modeling of all the variables of hydrologic cycle. Although field hydrogeological research and groundwater studies of karst aquifers in southern Italy has a long tradition starting from the 1960s, there is a lack of examples of equipped karst basins as natural hydrogeological observatories for continuous multiparametric field measurements in space and time of all hydrological variables of the water balance, such as precipitation, air temperature, infiltration, surface runoff, evapotranspiration, piezometric levels, and spring discharge.
In this study we present the Foce hydrogeological observatory (southern Italy), designed and implemented for the real-time estimation and modeling of the hydrological balance and groundwater recharge processes, as well as calibration of inflows-outflows models at the basin scale.

The Foce experimental karst basin, extended about 0,90 km2, is characterized by hydrogeological and environmental conditions typical of karst aquifers of the southern Apennine, i.e. steep carbonate slopes, fractured and karsified, covered with few meters thick by fall pyroclastic deposits and forest coppice. The experimental basin is located in the southern sector of Avella Mts. (Campania region), and locally hosts a vital groundwater resource for drinking water supply for about 1,500.000 inhabitants.

We provide an overview of the main physical and hydrological characteristics of the experimental karst basin and describing the installed instrumentation for the continuous monitoring of the following hydrological variables: i) precipitation and air temperature, by two weather stations located inside and outside the forest; ii) soil water content up to depth 1,20 m, by two multilevel probes; iii) water percolation and actual evapotranspiration, by a natural multilevel lysimeter with datalogger; iv) surface runoff, by a Venturi flume channel and radar sensor with datalogger; v) piezometric levels and spring discharges, by two levels and velocity sensors with datalogger.
Finally, we present the first results of multiparametric hydrogeological monitoring, characterization, and modelling to help advance the understanding real-time of non-linear recharge processes within karst basins with state-of-the-art modelling and monitoring tools, useful to implement adaptation strategies to climate change and a sustainable management of groundwater resources.

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Advancing groundwater recharge assessment in karst aquifers by coupling remote sensing and field hydrological monitoring

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Abstract

Remote sensing is recognized as the key approach for regional data collection, particularly concerning land surfaces and hydrological features like soil moisture and evapotranspiration. Satellite-derived data is invaluable in evaluating groundwater recharge, particularly crucial for the economic and social welfare which is closely tied to the availability of groundwater in the karst aquifers of southern Italy.

This research tends to expand traditional hydrogeological methods for estimating groundwater recharge in karst aquifers by integrating field monitoring and remote sensing data to understand the hydrological role of soil coverings. It was focused on the Mts. Soprano-Vesole-Chianello aquifer in Campania (southern Italy) which was considered ad a representative case study.

The research utilized Copernicus Global Land Services Soil Water Index (SWI) and Moderate Resolution Imaging Spectroradiometer (MODIS) Evapotranspiration products to evaluate soil water content and evapotranspiration patterns. Moreover, time series gathered by a monitoring network of 5 soil moisture probes since 2021 were examined. SWI1km offers daily soil water content at 1 km resolution, while MOD16A2 provides 8-day evapotranspiration estimates at 0.5 km resolution, using Penman-Monteith equation and MODIS data like vegetation dynamics, albedo, and land cover.

Both products encountered data gaps in mountainous areas of the karst aquifers due to algorithms considering factors like topography and cloud cover during product generation.

The key finding was the derivation of SWI values and the computation of a weighted mean (SWIw) based on 8-SWI values, factored by the quality factor. SWIw consistently displayed an approximate -20% difference from daily average field monitoring values. Despite this discrepancy, SWIw showcased an annual trend aligning closely (corr. > 0.68) with soil moisture probes measurements and effectively responded to rainfall events.

Additionally, MODIS ET data exhibited the evapotranspiration pattern, offering a temporal resolution difficult to attain without local meteorological data. To address the data gaps in the karst aquifer's mountainous regions, spatial interpolation of SWIw and MODIS

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ET was performed using various geostatistical techniques.

The findings suggest that SWI1km and MODIS16A2 enable soil moisture and evapotranspiration estimation for karst aquifers. Despite data gaps posing limitations, both datasets were proved valuable for advancing hydrological assessments of karst aquifer soil coverings and estimating groundwater recharge.

Keywords: remote sensing, surface soil moisture, evapotranspiration, karst aquifer, southern Italy

Applying graph theory on cave surveys to represent and characterize karst networks

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Abstract

Predicting karst aquifer responses to rain events or pollution is challenging due to the heterogenous and hidden nature of karst systems. At large scale, water flow simulations inside karst networks require a comprehensive knowledge of the geometry and connectedness of underground conduit systems. This knowledge is currently limited by our ability to explore and map caves, ignoring for example inaccessible cave networks. Since not all karst networks can be explored, we propose to use existing cave survey data to infer hidden karst network geometry. As part of a larger project aiming to test water flow laws in karst networks, we collect, clean, and process cave survey data from cavers to gather statistical information and simulate realistic karst networks based on external factors.

We use a simplified representation of karst networks to characterize them: graphs. In this mathematical representation, the conduits and their intersections are represented by nodes and links. To analyze the geometry and topology of these networks, we collect topometric cave data collected by cavers while they survey cave networks to help them draw the maps.

Up to now, we have collected open source and proprietary survey data for caves in Switzerland, Slovenia, and Patagonia, with the longer term objective to create a database of cave networks from around the world, spanning coastal, lowland and alpine settings.

Those cave surveys are graph representations of cave networks and are made of survey stations (nodes) and survey legs (links). The coordinates of the station surveys are calculated based on measurements of distance, vertical angle, and azimuth from one station to the other. As compared to previous work in this field, we incorporate additional geometric, geologic, and hydrogeologic properties to the nodes and links, based on cavers' observations. We then perform statistical analyses using Karstnet and Networkx python packages. This allows us to investigate whether the statistical distributions of conduit size, shape, length, and tortuosity, as well as their topological organization are evolving either within a single system (over the different phases of karstification) or among different systems.

Keywords: karst networks, graph

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[*]Speaker

Barite precipitation in a coastal karstic aquifer

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Abstract

The mixture of continental freshwater and marine saltwater in coastal aquifers, with very different properties, undergoes a wide variety of biogeochemical processes. A common process is the precipitation of some metallic mineral phases along the redox potential gradient between the oxic freshwater and the usually anoxic saline water. The relationship of these processes with microbial activity has been proposed by several authors but has not still been properly explored. Nevertheless, most of these studies cope with granular aquifers, but little is known about what happens in coastal karstic aquifers. In this work, two dolomitic rock cores that cut the freshwater, interface and saltwater zone in the Palmer aquifer (SE Spain) have been analyzed in order to recognize metallic precipitates on the discontinuity surfaces in a dolomitic matrix. In one of these cores, this surface is covered by Mn oxides coinciding with the strip of seawater, while Fe oxides are precipitated in the other core at the level of the interface. Both recovery cores come from piezometers close to the coastline with a position of the interface close to sea level. However, the thickness of the interface is notably greater in the piezometer that presents Fe oxides. Chemical analyses of these mineral precipitates indicate that, in addition to these two metals, there are high concentrations of Pb, Zn and Ba. Observation by means of a scanning electron microscope (SEM) shows that these precipitates have bacterial-type structures, so they would have precipitated through the intervention of microorganisms. Euhedral barite crystals are observed in one of the cores, together with Fe oxides. This barite would have been formed from Ba ions present in Fe oxides that would have been transformed into $BaSO_4$ by sulfation processes with groundwater. If these precipitates come into contact with a reducing aqueous medium rich in sulfide ions, the precipitation of metal sulfides such as sphalerite or galena could occur, giving rise to Mississippi Valley-Type (MVT) deposits. This work was funded by the projects PID2019-108832GB-I00 of the Spanish Government and UAL-FEDER2020-RNM-B1953, being also part of the general research lines promoted by the CEIMAR Campus of International Excellence.

Keywords: Dolomitic aquifer, barite crystal, MVT deposits, SE Spain

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Detection and quantification of fluorescent tracers using activated carbon detectors in groundwater

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Abstract

The activated carbon method is a quite old method which has been proved to be of a high practical and analytical potential. Factors of amplification as high as several hundredths have been observed in many cases. It is commonly used for groundwater tracing involving fluorescent dyes but it is always lacking a thorough scientific understanding and controlling, especially regarding its dependence on field conditions and extraction efficiency. The adjunction of spectral techniques to the method also led to a "false feeling of reliability and even sometimes blind application", without considering inherent uncertainties. Doubt and confusion often remain associated with charcoal results particularly if used alone. Due to their smart deployment, more convenient and inconspicuous than any other, charcoal detectors are unfortunately too often used without any validation by water sample analyses or high frequency data from field fluorometers. A lack of reproducibility due to the indirect, and complicate, processes of adsorption and extraction of the tracers is well recognized by experienced users, and it becomes a serious limitation when dealing with too few samples and targeting an answer such as "yes or no" while searching for hydraulic connections. In particular, the presence of an ambient fluorescence background due to organics, not only in karst waters, is always challenging and the use of blank samples is critical. The present study grasped the problem from both sides, implementing laboratory and field experimentation. Laboratory adsorption batch tests, mainly using fluorescein, were conducted inside a 1 m^3 tank, with controlled recirculation and agitation of water, as well as a continuous monitoring of concentration with a fluorometer and frequent water analyses. Several critical parameters such as concentration, flow velocity, background, pH, salinity, turbidity, type of tracer, and extraction procedures were tested through a serie of experiments quantifying adsorption and related kinetics on a daily, weekly and monthly scale between April 2021 and July 2023. Field experiments using variable test conditions started a few years ago, confronting systematically charcoal detectors with grab samples analyses and fluorometer data. Specifically known karst systems were chosen for that purpose in the Devonian limestones of South Belgium, as well as data from different case studies, in Belgium as well and in mining environments of the Peruvian Andes. All attempts made until now did not demonstrate a brilliant future for the detection of tracers other than fluorescein and eosin. The work highlights some of the determinants and uncertainties of the activated charcoal method and it hopefully opens the way to a wiser and more methodological application on the field, as well as in the laboratory. It should also give to the practitioner, whether hydrogeologist, speleologist or researcher, better responses on why, where, when, or how to use this technique, and especially which place this method definitely takes among others in terms of reliability of the achievement of tracing goals.

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Diurnal fluctuations of physico- chemical parameters in a cave stream of Grotta del Vento, Apuan Alps, Italy

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Abstract

Cave monitoring offers the possibility to directly investigate the groundwater dynamics either in the vadose zone or in the phreatic one of a karst system. Furthermore, high frequency and high precision monitoring allow recognizing small-scale phenomena which are usually neglected.

The Grotta del Vento cave is one of the most famous show caves in Italy. It is in the southeastern sector of the Apuan Alps karst area (NW Tuscany, Italy). It is mostly a vadose cave subject to impressive water table rises during major floods. A probe measuring water level (Lw), temperature (Tw), and electrical conductivity (ECw) every 15 minutes was installed in a small stream flowing in the lower part of the cave from June 2014 to December 2016. During the monitoried period, water level fluctuated in a range of 20-25 cm, which corresponds to a flow rate changing from about 0.3 to 40 L/s. Tw varied from 10.52 to 11.69 ∘C. ECw varied in the ranges of 189-288 μS/cm.

Despite being a mainly vadose creek, it showed an unexpected "piston" behaviour. In fact, ECw and Tw increased during rainfall-related water level rises. This behaviour indicates that at least a part of the recharge of this stream comes from a saturated aquifer characterized by a long residence time of groundwater.

Apart from the occasional rises due to precipitations, during persistent low flow conditions, Lw showed a cyclical fluctuation of 1-1.5 centimetres with a regular period of 24 hours. A similar fluctuation was showed also by the ECw and Tw. In non-disturbed periods, ECw and Tw were affected by a regular fluctuation of about 2-3 μS /cm and 0.03-0.04 ∘C, respectively. Despite the low amplitude of these fluctuations, this surprising observation implies that the cave stream feeding is regulated by a periodical phenomenon which determines a "micro-piston" effect at a daily scale. Such a behavior could be related to daily pressure atmospheric changes. In other words, we can suppose that atmospheric pressure controls the release of water from a perched saturated aquifer. This perched aquifer can be identified in a layer of carbonate tectonic breccias, about 100 m thick, which overlies the dolomitic marble where this cave is formed.

Keywords: karst hydrology, vadose flow, groundwater monitoring, percolation

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Establishment of an International Communication Network for the Practice of Karst Groundwater Tracing: Proficiency Testing of Fluorescent Tracers Analysis

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Abstract

Groundwater tracing with fluorescent compounds is a common technique among hydrogeologists, who need well experienced laboratories to insure the reliability of their results.An international group on tracers in hydrology was established under the auspices of the Karst Commission of the IAH during the Eurokarst conference in Malaga in 2022. The importance of fluorescent dye tracing practices was identified as a priority. A proficiency testing exercise was the first action of the group. It was started in September 2022, involving 11 international laboratories from Belgium, Brazil, France, Peru, Slovenia, Spain, Switzerland, United Kingdom and United States of America (Kentucky). Proficiency testing is a common practice in environmental analytical chemistry for assessing the value of a reference material, evaluating the accuracy of a given method, or the ability of the participants in the particular method of analysis. Its relevance depends on how far the conditions of realization are close to the real conditions and goals routinely faced by the laboratories. This testing

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is a first step towards a better standardization among practitioners, as well as a didactic exercise to help laboratories in their own evaluation or simply initiation. The specificity of tracer test analyses resides in the fact that one single analysis done on one single sample has little meaning, if not considered as part of the identification of a whole breakthrough of the injected tracer over time. Dye tracing, perhaps more than many other techniques, is a craft in which direct experience in the field and laboratory are an especially central part of learning. The accuracy of the analysis itself is usually not a main issue, except for pushing the limit of detection in order to reliably answer the question of the occurrence or not of hydraulic connection. A second reason why fluorescent dye tracing techniques need more intercomparisons is that nowadays laboratory analyses are often wedded to other techniques like active charcoal detectors or the new field fluorometer sensor technologies. Definitely, tracer test results depend on a high number of indissociable factors making proficiency very hard to evaluate. The present proficiency test was restricted to laboratory practices and included water samples of uranine, sulforhodamine G and amino G acid (2 concentration levels each, low and high, 2 replicates for each concentration), taken from same solutions prepared with a unique set of raw powders, and sent in opaque polypropylene containers. The same approach was carried out with undried samples of charcoal taken from a batch immerged during 8 days in identical ambient concentrations of uranine (3 concentration levels, 2 replicates). All freedom was left to the participants for analyzing the samples (use of reference material, method of analyses, calibration procedures, pre-treatments, delay...) but all conditions of analyses were carefully registered. The results of the analyses themselves have not been yet processed and are not likely to lead to any, for instance, statistical Z-score, but lessons were learned which emphasize the benefit of pursuing the international communication on this topic and the next steps will surely consist of more focused testing.

Keywords: fluorometric analyses, tracer tests, proficiency tests

EXPERIMENTAL SETUP FOR SCALING THE DYNAMIC OF INFILTRATION PROCESSES IN KARST AQUIFERS

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Abstract

Advancing the knowledge of infiltration processes in karst aquifers is crucial for a better evaluation of water resources as an adaptation to climate change. Nevertheless, quantitative information on factors related to the variability of effective recharge is still a poorly explored domain in hydrological sciences, as most authors have focused on indirect methods for global recharge estimation. This work introduces a new experimental setup deployed in Sierra de Segura, a karst region in southern Spain, to achieve a better understanding of the dynamics of infiltration processes and subsurface flows at different -temporal and spatial- scales.
Three automatic weather stations (WS), suited to mountain climate conditions, and four lysimetric plots (LP) were installed in selected sites with different characteristics regarding altitude, soil thickness, type of vegetation, etc., but also with a specific role in flow processes controlled by spatial scale. Each LP (400m2) contains an average of 45 single probes, vertically arranged in clusters of three (at 5, 10cm depth and soil-rock transition -average depth 25cm-), in randomly chosen profiles. Datasets from plots (soil-moisture and temperature with 15-minute step) were combined with hourly hydrodynamic and hydrothermal responses acquired at an epikarst and several karst springs. From the smallest to the largest scale processes, the experimental set-ups and some preliminary results are:

- WS+LP at 1910m a.s.l. (poorly developed soil, sparse shrub vegetation), 200m from an epikarstic spring (1870m a.s.l.). 6 to 7-hour delayed responses (maximum soil drainage time) were observed in the epikarst spring after soil-moisture peaks, depending on the rainfall intensity and quantity, but also linked to snowmelt processes, which contribute to understand the shallowest soil heterogeneity and the partitioning of rainfall-snowmelt/evaporation into infiltration.

- WS+LP (1645m a.s.l.), 1km from the main spring (1320m a.s.l.), draining an isolated carbonate aquifer with barely 6km2 of recharge area. Hydrodynamic response shows a direct relationship with previous soil-moisture conditions (effective recharge threshold -ERT-), but inverse with the temperature (seasonality/evapotranspiration) during recharge events. These results will help to precise soil water budget components and evaluate ERT.

- LP at 1340m a.s.l. (medium-poor developed soil, woody vegetation) over the same aquifer

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(60km2) as the first LP + several boreholes + two equipped outlets (at 1144 and 1090m a.s.l.), with a significant influence of the unsaturated zone (UZ) and the saturated zone (SZ). Springs respond after 4-9 hours or 14-18 hours after moisture peaks, according to the influence of the UZ and the SZ in the functioning of the outlets, respectively. Define the transference of the input signal through the vertically distributed compartments of the aquifer (soil-epikarst, UZ and SZ).

- WS+LP (1700m a.s.l.) at the centre of an approximately 200km2 endorheic area + four monitored karst springs (between 5 and 12km from LP). To study recharge processes with a regional perspective (larger scale), with 40-60% of estimated recharge rate, and where duality in recharge mechanisms (diffuse and concentrate) occurs.
From all these results, numerical modelling tools will be developed for a reliable prediction of water resources in carbonate aquifers under different climate change scenarios.

Keywords: Lysimetric plot, effective infiltration, scale effects, karst, climate change

Fluorescent dye tracing : Regulations and best practices in Europa - an overview

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Abstract

Fluorescent dye tracing is a valuable methodology commonly used by hydrogeologists to characterise karstic systems. The methodology has an advantage over other tracing techniques using isotopes, salt, or other microbiological or physico-chemical tracers present in the environment because of it's ease of use, specificity, relatively lower cost and less need of extensive lab analysis of water samples. An in-situ fluorometer, an automatic sampler, or active carbon bags followed up by a run through a lab spectrofluorometer can provide sufficient information. However, artificial fluorescent dye tracers need to be injected in the environment and can be liable to interpretation of the EU Water Legislation which stipulates that no 'artificial' substances should be added to natural water bodies. It is up to the EU member states to translate the EU Water Legislation into their national legislation, but fluorescent dye tracer tests are seldomly mentioned so regulations are very unclear. This leaves it up to scientists, public institutions, private companies, and local government bodies to determine if and how fluorescent tracer tests can be conducted.

Information on regulations, permit requirements, and best practices in the different EU member states, or the lack thereof, is already available, but the information is scattered or in need of an update. The goal of this research is to update and summarise the available information on fluorescent dye tracer tests on the topics of regulations, ecotoxicology of fluorescent tracers, and best practices. This way the research can serve as a valuable source of information to share and improve fluorescent dye tracer methodologies and serve as an information brochure for governmental bodies who might be less familiar and adverse towards this methodology as a result of a lack of knowledge on the methodology.

The method that will be used to conduct this research is a combination of legislative research, literature research on ecotoxicology studies of fluorescent tracers, contact with hydrogeology experts in EU member states, contact with research institutes specialised in fluorescent dye tracing tests.

Keywords: Fluorescent dye tracing, ecotoxicology, fluorescent dye tracers, best practices, regulations

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[*]Speaker

How Karst Geology Changes Expected Streamflow Regimes in Western Snowmelt Driven Watersheds

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Abstract

Analysis of paired precipitation (SNOTEL) and streamflow gaging data in the western United States shows that snow-dominated mountainous regions with karst geology store large fractions of annual snowmelt during spring runoff. These carbonate aquifers exhibit a spectrum of flow paths between karst conduits, sinkholes feeding cave systems that transmit water readily to spring outlets, to karst matrix, comprising fractured carbonates that store water in variably connected smaller fractures and voids. A well-connected karst aquifer will discharge a large portion of its accumulated precipitation to rivers and streams via springs and instream groundwater flow paths on an annual scale, while poorly connected karst aquifers will build up storage volume over multiple years and exhibit an above average streamflow response for extended periods when some critical aquifer volume is reached. We compare the groundwater storage regimes of western karst watersheds to their non-karst neighbors. In the Logan River watershed in Northern Utah, we further examine the spatial and temporal importance of in-stream karst groundwater contributions to streamflow using various approaches. In western watersheds where paired flow and precipitation data are available, analysis of normalized flow and cumulative precipitation in karst watersheds shows spring runoff volumes which are moderated due to karst aquifer recharge while baseflows are amplified due to karst aquifer discharge, while in non-karst watersheds, increased precipitation primarily affects spring runoff volumes. Over longer timescales, karst watersheds show the potential filling and draining of large amounts of karst aquifer storage, whereas in non-karst watersheds streamflow changes in response to changing precipitation. Detailed analysis of the Logan River shows significant groundwater contributions to streamflow in addition to karst springs, but these distributed inflow contributions vary with space and time. Communities in many western watersheds are dependent on snow dominated karst watersheds for their water supply. This analysis using widely available hydrologic data can provide insight into the recharge and storage processes of these watersheds, improve our ability to assess current flow regimes, predict the impacts of climate change on water availability, and help to manage water supplies.

Keywords: Karst, western United States, streamflow regimes

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How to discriminate between local and regional flows for the management of karst groundwater resources? Use of δ2H vs δ18O applied to the Huveaune watershed and the hydrogeological catchment of the Port-Miou spring, south-east France)

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Abstract

The management of surface and groundwater resources requires to define river watershed and groundwater recharge zones. Rainfall that infiltrates the recharge zone becomes groundwater, which can feed a local or regional flow. Regional flows represent a generally larger body of groundwater, which may be totally disconnected from the local river, thus becoming a resource of major interest. In Mediterranean karst aquifers, this type of regional flow is common, firstly because the geological structures are favorable (thick carbonates, structural discontinuities that connect superimposed or juxtaposed aquifers), and secondly because karst networks have been able to develop at depth towards paleo-outlets, for example in karsts linked to the Messinian event that drained the Mediterranean Sea.
When withdrawing groundwater with boreholes, it is therefore important to know what type of water the well intercepts. The challenge is to propose a method that can differentiate regional from local water flows. This is a major challenge, as we are often dealing with the same types of rock, which are therefore likely to give a similar geochemical signature as regard to major ions. Among the vast array of existing geochemical tracers, some are complex or expensive to analyze, such as strontium isotopes or water sulfate isotopes. So, although they are an interesting source of information on water-rock interaction processes, they are not systematically used. On the contrary, water isotopes (d2H and d18O) have the advantage of being easy to sample, and relatively easy to analyze. These isotopes are known to be good markers of recharge altitudes, or of mixing between water masses, or of the origin

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of water in relation to rainfall.

In this study, we present a groundwater characterization approach based on the d2H versus d18O plot, applied to the case study of the Huveaune watershed and the Port-Miou hydrogeological catchment area in south-eastern France, covering a vast area of around 500 km^2. Over a two-year period, 23 water sampling points (river, spring, borehole) were monitored for a total of 97 analyses, under a variety of hydrological conditions (low-water, flood, base-water, high-water). Water groups characteristic of local and regional groundwaters were thus established. Water recharged in the highest altitudes (between 500 and 1150 m above sea level) is characterized by a depleted isotopic signature, enabling it to be identified when collected by boreholes in the plains close to sea level. Four water groups were thus characterized. The graphical tool enables water managers to locate the water withdrawn in new boreholes, so as to easily assess the water mass intercepted by the borehole. We show that long-term monitoring of water isotopes in drinking water could help improve water management.

Hydrologic and Hydrodynamic characterisation via flow duration curves of the karstic outlet of Ain Zerga, Tebessa, North East of Algeria

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Abstract

This study set out to investigate the hydrodynamic of the karstic outlet of Ain Zerga, and to characterize its infiltration zone, based on flow duration curves (Mangin et al 1984). Thus the probability graphs of cumulative frequencies of flows in function of flow classes, presents a variety of discontinuous slopes reflecting a variation in the flow regime, are attributed to hydrological and hydrodynamic interpretation. Consequently, the own flow duration curve models of the karstic outlet of Ain Zerga, has revealed that the hydraulic inertia in short term, and long term is characterized by momentary storage, as well as to the functioning of overflow.Coversely to wet periods, reserves are constituted under slow infiltration condition, due to dephasing of infiltration as a result of snow melting, which forms auxiliary drainage systems that supply the karstic system during periods of drought

Keywords: Flow duration, karstic outlet, Ain Zerga, Dyr syncline, Algeria

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Identification and quantification of karst/river exchanges through physical and chemical characterization.

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Abstract

Most karstic systems are connected to rivers, and their respective hydrodynamics and hydrochemistry are often linked. This study is focused on the Célé River, which originates from the crystalline bedrock of the Massif Central and subsequently crosses the karstic limestone plateau of the Causses du Quercy in its terminal part before flowing into the Lot River. Approximately fifteen main karst springs feed the Célé in this segment. The geochemical fingerprint of the Célé and the karst springs differs. Therefore, the study aims to quantify hydrochemical markers and identify efficient methodologies to characterize and quantify karst-river interactions both spatially and temporally.

To achieve this, a spatial approach has been tested, involving measuring changes in physicochemical parameters (pH, turbidity, conductivity, temperature, and dissolved O2) at a tighter time step, using a probe mounted on a canoe along the karstic portion of the basin to spatially define the interactions between the karst and the river and optimize the use of identified markers.

During the first canoe campaign, we monitored the conductivity of the Célé as a primary indicator of exchanges between the river and karst, which increased from 175 μS/cm to 301 μS/cm between the upstream and downstream sections of the karstic area. The conductivity profile shows areas of significant increases at the spring locations and zones of variable growth rates depending on mixing processes. The results were segmented into different sections based on significant moving average changes or slope changes in the trend line. This helped distinguish fourteen sections where conductivity varied significantly: regularly increasing most of the time and decreasing in some sections, indicating areas of mixing with non-karstic origin.

This methodology has allowed us to identify new springs and determine sections of the basin

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[*]Speaker

where karst contributions are more significant. We have also observed increases in conductivity in the form of plateaus or linear increases. This would indicate punctual contributions and more diffuse karstic inputs.

Keywords: Hydrogeology, Karst, river interaction, Conductivity, Quercy, Hydrochemistry, Canoe

Investigation of groundwater-seismicity relationship in a karst aquifer: preliminary results from a new monitoring site in Southern Spain (Maro Spring, Andalusia)

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Abstract

Hydrogeological and hydrogeochemical studies focusing on the relationship between groundwater and seismic activity are growing over the years. Based on the promising results achieved in seismogenic areas, hydrogeochemical networks have been set up or are in progress in many countries worldwide to identify responses induced by earthquakes and to develop hydrogeochemical models associated with various geo-tectonic contexts. With the aim of deepening our understanding within a karst system, a scientific international collaboration started between the Department of Earth Sciences of Sapienza University of Rome and the Department of Ecology and Geology of the University of Málaga. To perform hydrogeological and hydrogeochemical monitoring related to seismicity, we selected Maro spring, which is the main discharge point of the Sierra Almijara carbonate aquifer located at Nerja in the Andalusia region (southern Spain), one of the Spanish regions characterized by the highest seismicity. Since December 2021, monthly sampling surveys have been ongoing to measure on-site chemical-physical parameters (Electrical Conductivity and Temperature) and to collect groundwater samples for hydrogeochemical analyses, including the determination of major ions, trace and rare earth elements, and isotopic composition (δ2H and δ18O). Additionally, a radon probe was installed in June 2022 to continuously detect the concentration of dissolved gas in groundwater. This long-term monitoring allowed us (i) to realize a comprehensive hydrogeochemical characterization of Maro spring and (ii) to build time series over the years of the parameters (e.g., major ions, trace elements, radon activity) potentially influenced by seismic activity. The Piper diagram shows that groundwater of Maro spring has a Ca-SO4 facies. Notably, its total mineralization exceeds typical expectations for carbonate environments. In fact, its high content of sulphate ions is ascribed to the dissolution of Mesozoic gypsum hosted in the carbonate formation. On the other hand, the analysis of hydrogeological, hydrogeochemical, and gas-geochemical time series revealed some significant changes in hydrogeochemical features through the comparison with rainfall data collected by the nearby rain gauge station and seismic data recorded by the Instituto

Geográfico Nacional. Preliminary results shed light particularly on the well-developed karstic condition that characterizes the spring, which responds quickly to rainfall with increasing radon concentration and fast dilution of hydrogeochemical content. Coupling discrete and continuous monitoring enables the identification of trends and periodicities, or "anomalous" signals. Hence, this approach facilitates a better understanding and differentiation between potential seismic responses (e.g., statistically significant changes of the measured parameters, recognized as the results of the interaction with seismic events) and "karstic" signals (e.g., variations associated with rainfall events). Furthermore, periodic hydrogeochemical screening of Maro waters contributes to assessing the quality of groundwater resources, enhancing drinking water safety, and addressing emerging contaminant problems.

Keywords: hydrogeochemistry, earthquakes, karst, monitoring, hydrosensitivity, seismicity

Karst Modelling Challenge: what is coming next?

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Abstract

The karst modelling challenge (KMC) was proposed to compare the various approaches developed worldwide for simulating groundwater flow in karst environments. The Purpose in STEP 1 was to simulate the precipitation-discharge process (Jeannin et al., 2021). For this exercise, fifteen groups applied different modelling approaches to the same data set (from Milandre Karst Laboratory). Data were limited to atmospheric inputs i.e. precipitation, temperature, potential evapotranspiration, and spring discharge for output. A first result was the definition of common criteria for the model comparison. A second result was that the models applied were all reasonably able to reflect the karst system hydrology. The third result was that there are clearly two main families of approaches, both being valid for simulating discharge rate variations at a karst spring from meteorological data.

1) **Data-driven models**, which are mostly not based on the physics of flow. They include reservoir models as well as mathematical concepts within the range of artificial intelligence (AI). Their fitting parameters have no physical interpretation and they can hardly provide information about processes taking place undergound, such as the spatial distribution of heads and flow velocity. To improve their models, researchers suggested considering more detailed input data (e.g. more rain-gauges), a longer duration for model-training, or indirect data (e.g. time series of physico-chemical parameters).

2) **Physically-based models** include physical descriptions of the sub-systems traversed by groundwater all over the 3D volume of the karst massif.Their fitting parameters are physical and are supposed to provide information about the internal flow dynamics (e.g., hydraulic heads and flow characteristics). To improve their models, researchers suggested using head and flow data form boreholes and caves, and also to improve the physical description of their models.

For STEP 2, focused on flow processes, we will form two groups having their own approaches

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and developments. In this step we expect to improve the simulation of spring discharge of Milandre and possibly to expand it to other karst springs. We will also simulate heads and flow velocities in the Milandre system, and simulate the effect of changes in climate and land-use.

Along STEP 2 we expect to better identify the limits of each approach and we might try to merge aspects of data-driven models with more physics based ones into a combined framework.

Such improvements will probably be necessary for starting STEP 3 in which we will deal with solute and heat transport.

All along the process, discussions and surveys are intended to identify a widespread range of likely purposes for model applications, including the identification of strengths and limitations of various model approaches depending on the intended model application. Finally, the findings and experiences will be merged in a combined framework of model types for the characterization of karst hydrogeological systems.

Any group of research interested in participating in this challenge is welcome. A meeting of KMC will be organized during the week in Roma.

Reference:

Jeannin, P.-Y. et al., 2021. Karst modelling challenge 1: Results of hydrological modelling. Journal of Hydrology 600, 126508. https://doi.org/10.1016/j.jhydrol.2021.126508

Keywords: Flow, modelling, flow systems, comparison

Karstic zones influencing the development and dewatering of an underground mine

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Abstract

Karst terrain is known worldwide for its anisotropy and heterogeneity. These regions account for 15% of the unfrozen terrain on our planet, and some mines of great economic value are located in these systems. This is the case of the Vazante and Extremo Norte underground mines of the Nexa Resources company, located in the town of Vazante, Minas Gerais State, Brazil, which exploits zinc and lead minerals in the region. The mineralization is trapped in dolomites of Serra do Poço Verde Formation and is extracted through underground galleries where is necessary to lower the level of the aquifer. In this way, the intensity and evolution of the karst zones present in the system have direct influence over the stability of the mine developments and in the dewatering process of the mines. This work is focused on the Extremo Norte underground mine, to understand and characterize the zones of greatest karstification currently present in the area, by on site geological and structural surveys,hydrogeological and geochemical investigations and direct investigations as borehole drilling. The characterization and identification of these regions makes it possible to identify areas that are potentially more susceptible to creating larger water and mud inflows into the mine. These zones with more intense karstification have open fractures that allow water and mud to flow mainly in the SW-NE direction, and currently they are restricted to being explored when located above the water level to avoid hydrogeological and geomechanical issues. In order to prevent these issues, the dewatering is made in a controlled way draining the aquifer through drain holes or directly on fractures. The water flows by gravity to underground reservoirs and from there it is pumped to surface. The actual geological model based on the data available gives a good safety margin to prevent geological and hydrogeological problems, however the heterogeneity of this kind of terrain makes these limits not always accurate. It can also be seen that some regions are connected to each other, demonstrated by variations on measured water flow rates, pressures and in suspended solids during nearby developments. Further detailed studies are still needed to better understand the dynamics of these regions and how to explore them more safely.

Keywords: underground mine, dewatering, Brazil, karst, hydrogeology

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Key technologies and scheme formulation for karst spring area restoration in Beijing, China

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Abstract

Increasing the groundwater reserves can not only improve the ecological and environmental quality, but also promote the revival of spring in karst areas. As for two dry karst springs called Yuquan spring and Baifu spring in Beijing China, there are some key questions need to be identified for their revival , which include the spring domain, the recharge and discharge of groundwater in this area, the relationship between karst water and quaternary groundwater, and the efficient path of karst spring system recovery. Here we use groundwater monitoring well construction technology, geophysical exploration technology, isotopic trace technology, hydrochemical analysis and numerical groundwater simulationmethod to determine the geological structure, stratigraphic lithology, and groundwater age . Meanwhile the groundwater diameter in Yuquan spring and Baifu spring area were analyzed, and the karst water and quaternary groundwater recovery scheme are discussed.In addition,The recovery time and the total storage groundwater for the two spring are determined. The results show that the karst water system of Yuquan spring has mainly three recharge areas, which are Junzhuang-Wenquan, Yongding River along Shijingshan,and Lujiatan along Babaoshan fault.The Baifuquan karst water system mainly consists of two recharge areas, which are the Taoyukou karst outcropping area in the northeast mountain and the Ming Tombs karst outcropping area in the northwest mountain in Changping district. According to the simulation and prediction of FEFFLOW, the total groundwater storage in Yuquan area before Yuquan Spring dried is 3.684 billion cubic meters, and it will flow out in 2050 under one optimized recovery scheme for karst water and quaternary groundwater. The total groundwater storage in the Baifu area before Baifu Spring dried is 1.3 billion cubic meters, and it will flow out by the end of 2034 under an optimized recovery scheme for karst water and quaternary groundwater. The results can effectively support groundwater reserves and restore the karst spring system for Beijing.

Keywords: karst, geophysical exploration technology, isotopic trace, numerical groundwater simulation, restoration

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Landslide susceptibility of fault zones in a karstified carbonate aquifer: the Grigna massif in northern Italy

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Abstract

In a changing world, climate change, characterized by an increase in heavy rainfall and alterations in precipitation patterns, plays a crucial role in exacerbating karstic phenomena. This significantly influences slope stability and increases susceptibility to landslides. Therefore, a detailed understanding of the geological model capable of identifying groundwater circulation is of paramount importance. With this aim, the present paper evaluates the susceptibility to slope instability as a consequence of fault zones hydrogeology in karstified carbonate aquifers located in the Grigna Massif (northern Italy), where large landslides often occur close to Fiumelatte Spring (the most important karstic spring in Lombardy), endangering a large area between Bellano and Lecco. The hydrogeological setting of the study area (about 100 km2 wide) is mainly controlled by its tectonic setting, which, in turn, controls both karst evolution as well as slope morphodynamics. In more detail, the study focuses on rock fall events occurred in recent years (the very last event was in 2023), affecting the carbonate ridge above Lario Lake near Varenna (Lecco District). The research aims to identify the main factors controlling the preparedness of this karsts area for slope instabilities, with specific reference to geological, hydrogeological and tectonic structures affecting slope dynamic. Based on tectonic and morphologic evidences, the study area is crossed by several joint sets, among which the most relevant one in karsts evolution and slope stability belongs to a set of subvertical faults known as Lecco Faults, having strike parallel to the Lake and causing a significant decrease in mechanical strength. The conceptual model of the groundwater flow has been developed following these steps: 1) data collection and filed surveys on karst and fault zones; 2) assessment of groundwater flow rate and pressure, and their effects on slope stability; 3) study of the correlation between slope instabilities and groundwater flow conditions. Results allowed a quantitative assessment of water flow and pressure at the catchment scale, enanching the development of a coupled (discrete flow and slope stability) model at the slope scale. The flow modelling results were compared to the landslide map of the study area in order to highlight landslide susceptibility related to groundwater conditions. This comparison showed that the N-S trending system of faults, creates a very peculiar groundwater flow pattern within the karsts massif, where fault zones convey groundwater flow toward the fault core, triggering local instabilities. As demonstrated by the slope scale model, high water flow rates and pressure (e.g., after heavy rainfall or during the spring season) can trigger block instabilities along the steep slopes of the carbonate ridge above the Lake. As a result, a landslide susceptibility map was drawn, in order to optimise the operational monitoring system, and therefore to further improve the conceptual model of the groundwater flow affecting slope dynamic.

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Mixing processes in a karstic aquifer drained through large springs; southwest Mount Hermon, Israel

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Abstract

Three springs located at the southwestern end of Mt. Hermon, are the main source of water for the Jordan River. The Dan, Banias, and Officer's springs (255 ± 39 MCM/Y, 69 ± 19 MCM/Y, 23.6 ± 2.4 MCM/Y, respectively) show annual hydrographs typical of a developed karst aquifer, i.e. increase and decrease in discharge according to wet and dry periods. The current study aims to present a conceptual hydrochemical model for the aquifer, based on its water composition, which will help in a better understanding of the regional hydrological system.
The Jurassic aquifer, built mainly of highly karstified limestone, is exposed in most parts of Mt. Hermon anticline (2,814 m) and dips sharply to the southeast where it becomes confined under younger rocks.

The three springs display a low and almost constant chloride concentration of 5-16 mg/L, and together with the young 14C and tritium ages confirm the rapid infiltration into the karstic landscape, which is poor in soil cover. However, SO4 concentrations, and to a lesser extent the Mg and Ca in the Banias and Officer's springs, show seasonal fluctuations inversely related to the discharge. SO4 concentrations reach 130 mg/L, with a d34S signal of 19-21‰, attributed to marine gypsum dissolution. On the other hand, the d34S of the SO4-low Dan spring is -2.4‰, which agrees with current rainfall values (~5‰) combined with some oxidation of sulfide ore deposits (pyrite, galena; -5.5‰), which are common in the Jurassic rocks. While the Dan spring is the outlet of the well-washed Jurassic limestone aquifer without substantial gypsum remnants, the Banias and Officer's springs drain two groundwater systems that mix in varying proportions. One system is a rapid flow through the Jurassic limestone (quickflow component of the recession curve of the spring hydrograph), which is more pronounced in the wet period, while the second system is a slower component, that prevails mostly in the dry season and flows through the deeper upper Triassic layers (baseflow component of the recession curve). This stratigraphic layer contains marine gypsum, dolomites, and volcanic rocks, which serve as the source of the high SO4, Mg, and Ca concentrations and the high d34S isotopic value. A long fault, along which a river channel has deepened, separates the Dan spring sub-basin from that of the Banias and Officer's springs.
The seasonal fluctuations in the SO4 concentration serve as clear evidence of mixing in varying proportions of two chemical endmembers: a fresh endmember represented by the Dan spring that flows through the Jurassic limestone, and a saline endmember representing flow

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through the Upper Triassic section. The saline endmember was identified in a deep well (1,431 m) drilled south of Mt. Hermon into the Jurassic limestone. The SO4 concentration in this well is 650 mg/L and stable. The well findings corroborate the existence of a deep and extensive karst aquifer characterized by low Cl and high SO4 content, which is hydrologically connected to Mt. Hermon. This aquifer is currently utilized for irrigation.

Keywords: Karst springs, spring hydrograph, geochemical processes, geochemical mixing, sulfur isotopes

Some considerations on the upgraded hydrogeological map of Albania, through an example from a karst area

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Abstract

Hydrogeological maps are precious tools for comprehending the hydrodynamics of aquifers, and essential elements for a proper management plan of groundwater resources. This is especially true in karst settings, where water is scarce or totally absent at the surface. In such territories, underground freshwater often represents the only available, high-quality, resource for locals. After many years of surveys and scientific research, the hydrogeological map of Albania was originally published in 1985 by Eftimi and co-Authors, summarizing the hydrogeological features of all geological formations throughout the whole country. Since then, additional research activities have been performed on the Albanian hydrogeology, including karst aquifers, and a deep knowledge about the national water bodies has been reached. This forced to integrate and upgrade the 1985 hydrogeological map, beginning by adjusting the geological classification based on permeability and transmissivity values. In this contribution, we will focus on a sample area to illustrate the changes occurring in the upgraded map, with specific reference to karst areas. It focuses on one of the most significant karst massif of central Albania, Mali Me Gropa, aimed at presenting the main changes with respect to the original hydrogeological map of Albania, and the advancements reached in the knowledge of the groundwater systems. Actually, during the last decades, and with an impressive increase in the last 10 years, many intensive caving explorations have highlighted the importance of several Albanian karst systems that reach water table, allowing direct monitoring of the underground resources. Including such data in the upgrade of the hydrogeological map results therefore essential. The karst map symbols will be standardized, following the indications coming from the mapping commissions of the International Union of Speleology. In addition, the limits of some superficial karst areas will be modified in function of specific features such as the degree of karstification, which, in turn, affects the infiltration rate. Further, karst springs will be classified in function of the discharge values and the salinity degree. Integration of specific karst features within the map will allow to reach a more detailed comprehension of the functioning of karst aquifers, since it is chacaterized by high anisotropy of the rock masses, requiring specific adaptation in investigating techniques. Therefore, collection of data derived from the combination of accurate multidisciplinary surveys (geological, hydrogeological, structural, geomorphological), including those derived from speleological explorations, is essential for the whole comprehension of karst system and for the correct management of karst freshwater resources.

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Structure and Functioning of Eocene Non-functional Karsts in the Montpellier Region. Example of the St Gély du Fesc-Matelles Synclinal.

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Abstract

In the Montpellier region, above the Jurassic aquifers, including the Lez aquifer, there are Eocene synclines containing a series of "Lutetian" palustrine limestones with a thickness of up to 300m. These aquifers remain little studied and exploited, even though they could represent an interesting complementary resource, particularly during the summer months. They are isolated from the underlying Jurassic karst by impermeable formations (Valanginian marls and lower-Lutetian layers) and often filled with (semi)impervious materials. Thus, their recharge is provided from infiltration on well-developed outcropping areas and from losses at the intersection of watercourses with the syncline slopes. Among these synclines, the carbonate syncline of St Gély du Fesc-Matelles corresponds to the filling of a roll-over half-graben with oligocene filling composed of clays and conglomerates. The combination of structural, hydrochemical, and hydrodynamic approaches through piezometry and flow measurement of watercourses has allowed an understanding of the aquifer's functioning. It exhibits karstic features but without an organized drainage network. Thus, observable cavities are not connected to drains, and pumping tests show similar behavior as a porous area. The cavity walls reveal remarkable ghosting features, probably associated with the locally chalky facies of the carbonate levels. This 40 km2 aquifer is mostly captive, with a general flow along the synclinal axis from Northeast to Southwest, drained by the Mosson River. The recharge, estimated at 3.5 Mm3, is provided mainly from infiltration but a part (10%) originates from downstream losses of urbanized areas. The facies is represented by calcic bicarbonate, and major elements don't show contamination. However, the presence of trace elements indicates low-level and local contamination associated to anthropogenic activities. The study of this aquifer revealed that the projects considering the exploitation of the "Lutetian" karsts in the Montpellier region for water supply, especially in establishing protection perimeters (PPR and PPPE), should take into account its particular structure in the context of rapid urban expansion.

Keywords: Nonfunctional karst, Eocene, Synclinal, Hydrodynamics, Hydrochemistry

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Study on the origin of Fuentes de Marbella hot spring, Southeast of Spain

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Abstract

The Fuentes de Marbella is the main spring in the province of Almería (SE Spain) with an average flow of 500 L/s. It is a thermal spring that has been linked by several authors to the Turón-Peñarrodada carbonate massif, located west of Sierra de Gádor. Between both carbonate massifs flows the Adra River, in whose bed the Fuentes de Marbella discharge, a few kilometers south of the Benínar reservoir. This reservoir suffers losses due to water infiltration that end up flowing into the Fuentes de Marbella, thus further complicating the hydrological model of the area. The Turón-Peñarrodada massif has an area of only 25 km2. This reduced infiltration area makes it unfeasible to consider it as the only feeding area for the spring. The analysis of major and minor ions in the water has allowed us to carry out its hydrochemical characterization. The water has a calcium sulphate facies. From the isotopic analysis of the oxygen-18 and deuterium content, it has been possible to determine the elevation of the recharge area of this spring, which would be located between 1300-1600 m a.s.l. This height is much higher than those of the Turón-Peñarrodada massif, so it would be necessary to consider another recharge area. The only relief that meets these conditions would be the western end of Sierra de Gádor, located 11 km from the Fuentes de Marbella. The thermal character of these waters together with very low values in carbon-14 would support the possibility that waters infiltrated in Sierra de Gádor would have circulated in depth under a thick sequence of metapelites. This groundwater would eventually emerge in the first carbonate reliefs cut by the Adra River, originating the Fuentes de Marbella. A new geological cartography including a structural interpretation carried out in this area support this hypothesis against the previously established hydrogeological model. This work was funded by the projects PID2019-108832GB-I00 of the Spanish Government and UAL-FEDER2020-RNM-B1953, being also part of the general research lines promoted by the CEIMAR Campus of International Excellence.

Keywords: Springs with distant recharge, Benínar dam, thermal spring, Sierra de Gádor

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TOPIC 2
Vulnerability and protection of karst groundwater
ORAL PRESENTATIONS

A comparative analysis of microbial metabolic activities in karst and volcanic-alluvial aquifers: insights from a field study

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Abstract

The growing significance of understanding groundwater resources from diverse scientific perspectives reflects the intricate interplay between geological, chemical, and biological factors. Integrating these perspectives is essential for developing comprehensive strategies that ensure the sustainable use and management of this vital resource.
This study was intended for a comparative analysis of groundwater samples from two distinct areas in Central Italy by collecting samples from karst and volcanic-alluvial aquifers, at three large springs in the carbonatic reliefs of the Southern Umbrian Apennine and four springs in the volcanic-alluvial formations outcropping in the Caffarella Park within the city of Rome. Lithological settings and the chemical concentrations of major, minor, and trace elements were combined with microbial cell abundance (total cell counts and fecal contamination) and the community-level physiological profiles (Biolog Ecoplates assay).

The chemical parameters indicated that most samples in both types of aquifers belong to the calcium bicarbonate facies, except for the karstic spring of Stifone, which belongs to the chloride-sulfate alkaline earth facies. The occurrence of E. coli and the high microbial load levels (> 105 cells/ml) in some samples from Caffarella, indicated non-compliance with quality standards for direct utilization. The microbial communities from Caffarella showed a higher metabolic potential and a well-developed capacity for breaking down carbohydrates and polymers, thus emphasizing a robust capacity for processing organic compounds. In contrast, the microbial communities in the karstic Umbrian springs, excluding Stifone, follow more conventional degradation patterns. Despite their activity, the communities hosted by karst aquifers exhibit lower mean values in comparison to their counterparts in Caffarella Park. This discrepancy in degradation efficiency implies variations in the microbial metabolic dynamics between the karst and the volcano-sedimentary ecosystems.

Keywords: groundwater, chemical facies, microbial ecosystems, metabolic potential, E.coli, central Italy

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Drilling and Cutting-based Vulnerability Assessment of Karst Aquifers: An Innovative Method for Practicality in Karst Protection

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Abstract

In the last two decades, several methods have been proposed to evaluate the vulnerability assessment of karst aquifers. While these methods have proven to be useful, there are still many uncertainties regarding the true nature of the subsurface karst, making the practical application of these methods doubtful. The most significant issue in the evaluation of aquifers is the impact of the karst aquifer system on the obtained vulnerability map. Factors such as climate, type of lithology, fractures, tectonics, and vegetation can be evaluated simultaneously to address the intrinsic vulnerability of karst. However, all types of flow systems, particularly epikarst, can have a significant impact on the behavior of potential pollution and their penetration into the aquifer. In this study, a new method has been proposed to evaluate karstic aquifers in the western part of Kermanshah province (Western Iran) by incorporating two additional factors: the type of drilling cuttings for water wells in karstic aquifers and the flow system in the nearest discharge of karstic waters with hydrograph analysis. The results of 30 drilled wells and 50 karst springs were used to evaluate the vulnerability of the area. The outcomes of this study showed that vulnerable areas in sinkhole zones in high karst plateaus, Asmari, Bisotun, Shahbazan formations, and Imam Hassan limestone member can be local but severe. In contrast, vulnerable areas in Teleh Zang formation and exposed karst are wider but milder. The results of this study indicate that the vulnerability of karst aquifers is correlated with the flow system within the karst. Pollution susceptibility is high in conduit flows with open surface passages like sinkholes, shafts, and caves with entrances exposed to the open space. Conversely, the contamination risk in the internal conduit system of the aquifer is lower compared to the diffuse system. Thus, the presence of fractures and joints, along with the type of flow, can serve as a significant indicator of vulnerability. Detecting signs like fall drilling rods, failure of cuttings to rise, or changes in drilling pressure may suggest the development of solutional spaces in the aquifer. In the absence of a well-designed protection system, the well itself can become a conduit for pollution transfer, increasing the risk of contamination. These findings suggest that the proposed method can provide more accurate and practical results for evaluating the vulnerability of karstic aquifers, taking into account the specific characteristics of the area. In addition, the results of this research can be used as a map of the practicability of drilling in karst formations for use by local managers and decision-makers in the water sector. Areas with high vulnerability can have more productive drilling conditions than areas with less vulnerability.

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Keywords: Aquifer Vulnerability, karst, GIS, Kermanshah

Effects of Global and Climate Change on the Movement of the Freshwater-Seawater Interface in the Serres de Llevant range and the Marina de Llevant Karst Aquifers in Mallorca Island, Spain

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Abstract

Karst aquifers are globally vital freshwater sources, presenting a critical challenge for sustainable water resource management. In the context of Mediterranean coastal karst aquifers, characterized by a double-flow model (and even triple), their dynamic nature renders them highly responsive to chemical variations and groundwater level fluctuations. This sensitivity is particularly pronounced in coastal regions where aquifers exhibit an extensive subsurface conduit network linked to the rock matrix, facilitating groundwater discharge to the sea. Consequently, these aquifers are susceptible to seawater intrusion, with rapid responses to rainfall and pumping, making them highly sensitive to short-term weather variations and long-term climate change. The Mediterranean region, grappling with water scarcity and stress, faces the compounding impact of climate change-induced warming trends and reduced rainfall, exacerbating water availability issues. Additionally, rising water demands from agriculture, urban development, and the growing tourism industry further intensify water stress. Focusing on Mallorca Island in the western Mediterranean Sea, our study aimed to analyze the environmental implications of global and climate change on seawater intrusion in Mediterranean coastal karst aquifers, with a specific emphasis on the role of the double-flow pattern. Employing various methodologies, including hydrochemical techniques and multi-isotopic analysis, we investigated isotopes such as 2H and 18O in water molecules, 87Sr/86Sr ratio, Sr concentration in water and rock, B concentrations, $\delta 11B$ in water, $\delta 15N$ and $\delta 18O$ of nitrate in groundwater, and $\delta 34S$ and $\delta 18O$ of sulfate in both groundwater and gypsum Keuper facies materials. Our most significant results include the following: 1. Nitrate in groundwater or Freshwater-Seawater Interface iginates from agricultural and urban sources. 2. Reducing conditions linked to denitrification processes may occur in zones of seawater intrusion penetration. 3. Sulfate isotopic composition indicates hydraulic connections in the lower hydrogeological complex of the Serres de Llevant, linking Jurassic dolostones

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and limestones to underlying Triassic materials. 4. Partial mixing of freshwater with brackish water near the freshwater-seawater interface or salt-water domes can lead to significant problems, particularly in agriculture, contributing to soil sodification. 5. The rebound effect, characterized by aquifer recontamination due to molecular back-diffusion after the cessation of extractions and marine intrusion retreat, provides insights into the impact of climate and global change on Mediterranean karst aquifers. To conclude, our study underscores the vulnerability of Mediterranean coastal karst aquifers to the complex interplay of global and climate change, emphasizing the need for sustainable water resource management strategies in the face of evolving environmental conditions.

Estimating atmospheric CO2 uptake by carbonate rock weathering in the Mediterranean Humid continental karst basin

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Abstract

Carbonate rock weathering is a known sink of atmospheric CO2 (IPCC AR5), while studied well in China, a few studies look at it in Europe. As an example, the 551 weir long-term observation site in the Zöbelboden region of Austria, where the climate is humid continental and the dominant geology is a Norian dolomite (Hauptdolomit), was analyzed for CO2 uptake by carbonate rock weathering from 2000-2019. The results show that the watershed cations are dominated by Ca2+ and Mg2+, and the anions are dominated by HCO3-. The concentration ranges of the three ions were 33.00-52.96 mg L-1, 18.00-29.50 mg L-1 and 166.43-263.83 mg L-1, respectively. The concentrations of Ca2+ and Mg2+ were relatively stable over the past 19 years, while HCO3- showed a fluctuating growth trend, with the highest increase of 7% in the annual average value. According to the equation for carbonate weathering, the amount of CO2 uptake through this process is equal to half the product of the runoff and the HCO3-.The annual average value of CO2 uptake was calculated to be 0.081-0.261 t C ha-1a-1, and the value was controlled by the runoff, reaching the maximum value in 2009. Compared with the humid, hot and rainy subtropical monsoon dolomite watershed in southwestern China, where the HCO3- concentration (250.1-353.8 mg L-1) is usually higher, the amount of CO2 uptake by weathering of carbonate rocks is very similar (0.131 *vs* 0.137 t C ha-1a-1) at the same period. Higher Zöbelboden regional rainfall and snow recharge to the basin and lower evaporation probably are the reasons why this site has higher carbon sink. Zöbelboden Date from Environment Agency Austria(EAA) https://deims.org/8eda49e9-1f4e-4f3e-b58e-e0bb25dc32a6

Keywords: Carbonate rock weatheringAtmospheric CO2 uptakeMediterraneanSouthwestern China

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Evaluation of nitrate behavior, transport and storage in 5 karst aquifers of Wallonia (South Belgium)

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Abstract

The Epukarst project, financed by the Société Publique de Gestion de l'Eau (Wallonia) between 2020 and 2023, aimed at assessing the nitrogen behavior in the different compartments of karstified limestone aquifers with an experimental and participative approach.
Five karst watersheds with penetrable caves and major karst springs were studied in south of Belgium. The objective was to sample variable compartments in order to evaluate nitrogen concentrations (nitrates, nitrites and ammonium), but also transport and storage in each karst compartment : swallets, unsaturated zone (drip-points, gours), underground rivers and karst springs.

To carry out field sampling, local cavers teams were involved. Measurement tools and techniques were selected and tested with interlaboratory tests in order to validate analysis methods. Each team was equipped and formed to carry out a 3-years long sampling task on the field.

The results from 3 years of measurement over 5 karst systems demonstrate similar behavior between the same compartments in each of the watersheds. Nitrogen concentrations at the swallets are often significantly lower than the karst system spring, however those points are often see as high risk points in terms of aquifer vulnerability. The sampling in the unsaturated zone showed significantly higher nitrate contents compared to the mean value at the outlet. This illustrates the importance of the unsaturated zone in the transfer and storage of nitrate inside karst aquifers. Vadose zone is the main contributor to the nitrogen's karst aquifer concentration. Systematically, the nitrogen flux from the karst aquifer degrades the water quality of the receptive water body.
Based on the methodological approach and in order to benefit from those lessons in a more applied objective, the Epukarst project will further focus on 5 karst basins that are used for drinkable water distribution. Those basins have problematic qualitative status regarding nitrogen. During 2024-2027, the projet will apply a high temporal resolution measurement

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*Speaker

of nitrogen at the karst outlets, while keeping the focus on variable compartments behavior across the karst aquifer. In addition, dedicated measurements into agricultural lands at the surface will be used to inform about the nitrate input with a more refined approach. The aim is to be able to evaluate more precisely the correlation between agro-environmental actions and the response of the karst aquifer outlet. The quick reaction of karst aquifer and the knowledge about its quantitative behavior allow to precise the effect of the actions, their efficiency at short time scale and to objectify their implementation towards local stakeholders and decision-makers.

Keywords: nitrogen, nitrates, unsaturated zone, field sampling, agriculture

Exploring Climatic Change Scenarios and Aquifer Recharge in southern Italy

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Abstract

Climate change will impact groundwater availability by altering the hydrological cycle. Therefore, assessing groundwater recharge from changing precipitation and air temperature is becoming fundamental for shaping effective policies of groundwater management in the next decades. Reliable predictions of the available groundwater resources are crucial, especially in regions like southern Italy, which are heavily reliant on groundwater for societal and economic needs. This study aims to assess impacts of future climatic change scenarios on groundwater recharge from Regional Climate Models (RCMs) data over the principal 40 karst aquifers of southern Italy. According to the purpose of this research, we used both the time series of precipitation (P) and air temperature (T) of a 15 RCMs ensemble for the historical period (1950-2005) and scenarios projections (2006-2100). The RCMs ensemble was bias-corrected by the statistical comparison with the observed time series collected in the historical period (1950-2005) by the high-density meteorological network (311 rain gauges and 155 air temperature stations), managed by the National Hydrographic Service. Annual hydrological balances were computed for both the historical period and the IPCC Representative Concentration Pathways (RCP4.5 and RCP8.5) scenarios based on mean annual values of evapotranspiration (ETR), estimated by Turc equation, and effective precipitation (P-ETR). Data used derived from the RCMs of the EURO-CORDEX project with a spatial resolution of 0.11∘ (˜12 km) covering both the historical period and future climate scenarios until 2100. The assessment of future impacts on groundwater recharge was carried out by the estimation of the Annual Groundwater Recharge Coefficient (AGRCRCM), which correspond to the ratio between groundwater recharge and effective precipitation (P − ETR) derived from RCMs. At this scope, four representative karst aquifers were selected bases on the availability of consistent measurements of spring outflows. The values obtained, whose spatial resolution depends on that of the RCMs, were then employed to develop an empirical model for assessing the AGRCRCM and mean annual groundwater recharge scenarios in the other 40 regional principal karst aquifers. Lastly, the analysis of groundwater recharge was carried out for both RCPs scenarios for three consecutive 30-years periods: 2011–2040 (short term), 2041–2070 (medium term), and 2071–2100 (long term). As a first outcome, the AGRCRCM was estimated ranging between 59% and 93%. The mean annual groundwater recharge for the historical period was determined through these characterizations and subsequently validated by comparing it with existing measurements of groundwater outflow. The climate model projections, in comparison to the mean value of the historical period (1950-2005), show a gradual decrease in groundwater recharge across the region in the short term

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(2011–2040), medium term (2041–2070), and long term (2071–2100). The most substantial decline, exceeding 40%, is observed for the RCP 8.5 scenario for the long term period (2071–2100), instead, a decrease of 15% for the RCP 4.5 scenario. These findings contribute to a more comprehensive understanding of the prospective groundwater hydrological patterns of karst aquifers of southern Italy allowing to increase the awareness of the effects of climate change on the availability of groundwater resources.

Formation Mechanism and Countermeasures of Urban Karst Collapse

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Abstract

Karst collapse, usually called as sinkhole, is a major geological hazard in karst cities. In China, with a karst area of 3.61 million square kilometers, and among 287 cities at Prefecture-level, 66 have serious karst collapse problems. There are over 3900 documented karst collapses across the country, mainly distributed in southwestern, southern, and central regions. Due to its concealment and suddenness, the occurrence of karst collapse is often difficult to prevent, posing a great threat to residents' lives and property, as well as the safety of urban infrastructure. It has become the main geological environment problem faced by urban construction and development in karst areas. This article mainly introduces the following main achievements made by the author's research team in recent years with the support of the China Geological Survey in the survey of urban karst collapse. Firstly, the survey results show that the majority (80%) of urban karst collapse in China is related to engineering activities, and foundation pit engineering, pile foundation engineering, and subway tunnel construction are the main engineering factors that induce karst collapse; Secondly, the monitoring results indicate that the significant decrease or severe fluctuation of water and gas pressure in the karst conduit system caused by the pumping and impact of karst groundwater during construction is the main mechanism inducing karst collapse; The third is to propose a technical approach to effectively reduce and prevent urban karst collapse problems through high-precision monitoring of karst water and gas pressure to guide the optimization of engineering construction plans and processes.

Keywords: karst collapse, sinkhole, geohazard

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Geoconservation state and antropic impact evaluation of the Lagunas de Ruidera river-lake karstic system (Central Spain)

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Abstract

The Lagunas de Ruidera river-lake karstic system, located in the SE sector of the Iberian Peninsula, consists of a set of 15 stepped lakes, along a river valley that strikes NO-SE over the Campo de Montiel carbonatic aquifer. The natural travertine barriers -created by carbonate precipitation processes- associated to the lakes act as dams and are composed of different generations of travertines related to warm stages of the Upper Pleistocene – Holocene. Environmental changes and the historic human activity in the region, have notably modified the natural hydrological functioning of the system, with several processes and impacts the deteriorate and destroy these vulnerable geological formations. In this work, a study of the current geoconservation state of the lakes is presented. The objective of the work is to stablish a gradual restauration process of the lakes, with the purpose of returning this Protected Natural Site to a morphological and functional state as close as possible as the original. These actions are based on the adaptation to the global change, compatible with the socioeconomical activity in the region. A two-stage plan has been developed: Firstly, the current functioning of the system has been studied, in its altered state, and secondly, the anthropic impacts that affect the lakes have been identified and studied. The study of the current functioning of the system includes a hydrological and hydrogeological in-depth analysis, and the impact study includes the use of drones for the morphometric determination of the lakes and barriers. A zonation map of the geoconservation state has been developed, with 5 levels of impact. The results of the study evidence important degradations in the travertine barriers.

Keywords: groundwater, karst hydrogeology, travertines, Protected Natural Areas, Quaternary

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Groundwater quality evaluation and source analysis in typical karst areas

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Abstract

Na+, Cl–, SO42–, NO3–, NH3-N, Fe, F–, COD, Cu, Mn, Zn, Hg, and Pb were monitored in groundwater in Guilin City from 2017-2019. The study aimed to analyze their spatial and temporal distribution and sources. The findings indicate an overall improvement in water quality in Guilin during the period 2017-2019. Temporal changes reveal a general enhancement, with pollution being more pronounced in the western region compared to the east. The implementation of policies in 2017, such as centralized disposal of pollutants and improved industrial wastewater management, significantly improved water quality in the industrial area of the East District. The East District, known for its high degree of karst development, good hydraulic conductivity, and strong dilution and self-purification abilities, exhibits better water quality due to the difficulty of pollutants accumulating in the groundwater. The evaluation of groundwater quality in Guilin City from 2017 to 2019 revealed an increase in the diversity of pollutants over time. In 2017, only NO3– reached a strong level of pollution according to the single-factor pollution index. In 2018, NO3–, COD, and Mn were identified as pollutants, and in 2019, NO3–, COD, Mn, Hg, and Pb were found to be the main pollutants. The single-factor pollution evaluation indicated that NO3–, Mn, and Pb showed more severe pollution in 2019. Higher concentrations of NO3– in agricultural and residential areas may be attributed to the use of agricultural nitrogen fertilizers and infiltration of domestic sewage. Sampling points with higher Mn concentrations were found near the water system, possibly due to the discharge of Mn-containing wastewater. Pb was mainly distributed in sampling points located in populated areas. The correlation analysis reveals that NO3– primarily originates from agricultural sources, while Pb is mainly emitted from vehicle exhaust, domestic waste, and agricultural sources. Mn, on the other hand, can be traced back to geological sources, as well as industrial and domestic wastewater. Consequently, it is imperative to analyze and mitigate the levels of NO3–, Mn, and Pb in groundwater to safeguard the well-being of the local population.

Keywords: groundwater quality evaluationsource analysisheavy metals, karst groundwater

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Hydrologic Confinement Between Two Karst Hydrogeologic Units in Central Texas, USA

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Abstract

Studies have recently demonstrated the amount of vertical hydrologic confinement between two karst hydrogeologic units in the Cretaceous Trinity geologic units of central Texas. The hydrogeologic units being studied are the Lower Glen Rose and the underlying Cow Creek which are part of the Middle Trinity Aquifer. Within the study area, the Lower Glen Rose Limestone receives recharge through numerous fractures, sinkholes, and caves. Most of the recharge to the Cow Creek comes from lateral flow within the Cow Creek Limestone which is the principal hydrogeologic unit of the Middle Trinity Aquifer. Overlying the Cow Creek Limestone is the Hensel Formation which, in the study area, consists mostly of dolomite and serves as a confining unit. Confinement by the Hensel is reduced where vertical fractures cut through the Hensel. One example of this is at Jacob's Well Spring where a significant cave has developed along a fracture that provides a connection between the Cow Creek Limestone and the Lower Glen Rose Limestone. Jacob's Well Spring is a significant conduit/cave system that drains the Cow Creek Limestone over much of the study area.
Two multilevel wells were installed upgradient of Jacob's Well Spring and cross gradient to the conduit/cave system. One of these wells (JWNA) is a dual completion well with an open-hole completion within the Cow Creek Limestone and a piezometer installed in the Lower Glen Rose Limestone. Pressure transducers were placed in each of the two zones to provide continuous measurements of water levels. The second well (Coleman's Canyon) is a multiport monitor well that was completed with a total depth of 165 m and 10 monitoring zones. Water-level elevations are measured in each zone every two to three months.

Differences in water levels between the Lower Glen Rose and the Cow Creek indicate that there is hydrologic separation between these two units and that the Hensel Formation provides that separation. As measured in the multiport well, water-level differences between the two units over the period of record average about 0.7 m. As measured in the dual completion well, water-level differences average about 1.8 m. Over time, water levels change in both units but water levels in the Lower Glen Rose are consistently higher than those in the Cow Creek. At Jacob's Well Spring, about 0.7 km south of the JWNA dual completion well, heads are reversed with greater heads in the Cow Creek which allows for flow of groundwater upward through the Hensel where it discharges from the Lower Glen Rose at the surface. This is most likely due to the lower elevation of the entrance to the Jacob's Well Spring cave and the southeasterly dip of the beds.
During periods of drought, pumping from public water-supply wells is causing cessation of

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flow from Jacob's Well Spring. A detailed understanding of the aquifers and the hydrologic relationship between these aquifers is needed to be able to determine the sustainable yield of the aquifers which are under stress because of rapid growth in the area.

Italian karst springs in the MIKAS Project

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Abstract

Within the framework of the Most Important Karst Aquifer Springs (MIKAS project, leader Zoran Stevanovic), the hydrogeological features of the main karst springs of Italy are here described.
Along the Alps and Apennines many karst aquifers feed springs, both in the high-elevated zones and along the valleys. The latter generally constitute basal karst springs and drain wide portion of the saturated zone of carbonate aquifers, bounded by main faults, impervious terrains or alluvial deposits.

Even though the most well-known Italian karst is located in the Friuli region, eastern Alps -known, in the "Classical Karst", huge karst springs with relevant economic and historic importance are also located in the central-southern Apennines. These springs are controlled by the Mediterranean climate, and characterized by long, dry and hot summers, which induces a typical recession in the spring hydrograph, after the recharge period of winter-spring seasons.

Thanks to huge water reserves, these karst springs guarantee high discharge also during droughts. These aspects have had great importance in the historical and economic development of many regions of Italy, as well as for its civilizations, as in the whole Mediterranean area as well. Some karst springs have annual mean discharge higher than 15 m3/s (Timavo, Peschiera, Gari, Montoro-Stifone), other exceed 4 m3/s (Le Capore, Caposele, Aqua Marcia, Tirino, Capovolturno, Grassano, Capo Pescara, Posta Fibreno), and many other exceed 1 m3/s. They generally are characterized by a high base flow component, whereas the quick flow component appears to be dependent upon local hydrogeological factors, as karstification degrees and tectonic setting. Chemical-physical characteristics are strictly function of the hydrologic dynamics of the aquifers. Along coastline karst areas, brackish springs are mainly present in Apulia, Campania and Sicily.

The most powerful karst springs were easily tapped, and gravity channels allowed water to be supplied to high concentrations of people. Ancient Rome and its empire are the most significant examples, and still today millions of people are supplied by karst springs in the Latium, Abruzzo, Molise, Campania, Apulia, and Basilicata regions. In addition to those supplying Rome, the Apulian and the Serino aqueducts, more than 100 years old, are the

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most remarkable. The first has allowed to supply a semi-arid area, and constitutes one of the largest hydraulic systems in Europe without any pumping (energy free) for long distance. The second supplies the urban area of Naples, and was also a famous ancient aqueduct during the Roman empire.

Summing up, Italy is characterized by diffuse and powerful karst springs, holding a strong relevance from many points of view, including, but not limited to, economy, history and ecology.

Keywords: Karst spring, Mikas project, Italy

Karst springs in Brezovské Karpaty Mts. (Slovakia): differences in sensitivity to drought impact

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Abstract

During the summer period of 2022, the territory of the Central Europe overcame one of the driest periods without precipitation in the history of relevant records. The demand for water resources and legitimate concerns about their sustainable use initiated a study evaluating the quantitative durability of karst springs, which in Slovakia represent more than 50% of the resources feeding the water supply network. Brezovské Karpaty Mts. (West Slovakian Carpathians) with outcropping masses of Triassic limestones and dolomites and 26 karst springs were selected as a study area. An inevitable base of such an assessment is existence of regular monitored network of springs' discharge, which – in this case was carried out in surprisingly detailed observations since 2005 by regional water company Bratislavská Vodárenská, as well as by Slovak Hydrometeorological Institute in several cases, but in longer time span. The key instrument for evaluating the quantitative sensitivity / resistance of springs to long-lasting drought was the compilation of springs' recession curves from existing time series of yields and their description by relevant equations that take into account the presence of several flow components ("subregimes"). Techniques for separating the falling sections of hydrographs as well as the selection of relevant equations can vary – in our case, HydroOffice software product and the application of hybrid genetic algorithms which is provided here were used to construct a typical master recession curve for each individual spring. Exponential equations were chosen to describe slow flow (laminar) components, sets of linear equations were chosen to describe quick flow (turbulent) outflow components. The final form of the equations describing the recessional process of springs' discharge was calculated by iteration to the maximum observed yield value as exponential equations do not have an analytical solution and compiled master recession curves may not necessarily include the absolute maximum discharge documented in the entire observation period. Theoretical drop in springs' discharges from their recorded maxima, assuming zero recharge in their infiltration areas (a long-lasting period without precipitation, or at least without effective/non-evaporated precipitation) was calculated only then, by substitution of time from 1 day to 30 years in equations. The observed average discharge values Q-AVG for the entire set of evaluated springs was (theoretically) reached after recession lasting approximately 1 year from the observed maxima Q-MAX. Threshold of 0.1 Q-AVG (10% of the average discharge) was reached for the whole set after 7.3 years from the absolute maximum QMAX., or 6.3 years from the time when QAVG was reached. We consider the value of 0.1 Q-AVG to be a limiting threshold for the emergency state / absolute threat due to lack of groundwater resources, as well as the period of 6 years of lacking recharge to be crucial in the case of Triassic carbonate aquifer of the Brezovské Karpaty Mts. However, several

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springs here have reached zero discharge (or the limit of 0.01 l/s for laminar runoff components) already within one year, one of them even after 90 days, what is usual phenomenon for karstified aquifers.

Managing groundwater resources in a karstic environment – Approaches for addressing groundwater vulnerability and public water supply in the outskirts of London, UK

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Abstract

The Chalk is a biogenic limestone and an important aquifer for the Southeast of the UK, as it provides baseflow in ecologically sensitive Chalk streams and supports significant groundwater abstractions for public water supply purposes. The dominant flow in the Chalk occurs in the fracture and fissure network, developed especially along the river valleys with enhanced transmissivity. However, near the contact between the Paleogene deposits and the Chalk, where slightly acidic runoff from the low permeability Clays enters the Chalk outcrop area, there is typically enhanced karstification. This results in the development of sinkholes and depressions at surface, hence affecting the geomorphology and changing the course of intermittent rivers, whilst rapid flowpaths both in the unsaturated and the saturated zone, are also known to occur. This study investigates the impact of karst development on public water supply boreholes located in Chalk groundwater catchments, that are seasonally dominated by surface water runoff.

A case study in the outskirts of London, UK is used to identify the recharge mechanisms, using water level measurements in observation boreholes installed at different depths in the Chalk aquifer. Water quality parameters are also monitored and used as indicators of recharge and abstraction impacts. Results show that there is dual piezometry in the Chalk and changes in abstraction highlight the importance of an adit system present in the deeper Chalk layers, that acts as a horizontal drain to the lower layers of the Chalk, with limited contribution from the upper layers. This is due to the presence of aquitard units, causing the upper aquifer to act as leaky. However, due to the karstic nature of the Chalk in the wider area, following high intensity rainfall events, the deeper Chalk units respond first to rainfall/recharge, as indicated by the rise in the deeper groundwater level, while the upper layers do follow the same pattern delayed by approximately 24 hours. This indicates the presence of sinkholes that cause by-pass recharge, while water quality parameters such as turbidity, indicate similar responses in the pumping boreholes.

A second case study in the same catchment shows the impact of sinkholes on the raw groundwater quality at nearby abstraction boreholes, following rainfall/runoff events. This deterioration is even more prevalent in the winter months following the application of salt/grit in the nearby motorway network. The accumulation of salt during cold and dry periods, combined with the subsequent high intensity rainfall/runoff events, cause high salinity runoff water to enter the river network and drain into the sinkholes. This in turn can increase the salinity of

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groundwater, impacting on the treatment works and causing outages at nearby public water supply boreholes.

This study demonstrates that enhanced conceptual understanding of the hydrological processes in a river catchment can provide suitable ways of monitoring and managing the climatic effects in a vulnerable karstic groundwater system.

Keywords: Chalk stream, By, pass Recharge, Sinkholes, Turbidity, Salinity

Response to pumping of wells in carbonate and karst aquifers and effect on the assessment of sustainable well yield: some examples from southern Italy

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Abstract

Carbonate and karst aquifers are of great importance for human water supply, for supporting aquatic habitats and for providing ecosystem services. Optimize the groundwater withdrawals from these aquifers is therefore essential to obtain maximum flow rate for human purposes and at the same time to limit the negative effects on the environment. In particular, when the abstraction of groundwater occurs through wells, the problem of defining the sustainable yield arises, i.e., the pumping of groundwater in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic and social consequences. This is therefore a complex issue, but clearly the definition of the sustainable well yield must necessarily be based on the aquifer response to pumping. This study accounts some pumping tests carried out in carbonate and karst aquifers of southern Italy to derive indications for defining the sustainable yield of wells. The four examined cases concern Mesozoic-Cenozoic platform and transition-pelagic carbonate rocks characterized by different degree of fracturing and karstification. The pumping tests were performed on about 30 wells, measuring the drawdown in the pumping well and often also in observation wells, with a duration lasting from several hours to few days. The drawdown data versus time were analyzed through semi-log plots, while the smoothed time series were represented on bi-log plots together with the first derivative of the drawdown. The trends of drawdown-time and its derivative were compared with theoretical curves identifying the flow dimension. This qualitative diagnosis allowed to select the most consistent conceptual models for the measured data according with the geological and hydrogeological settings of the test site. Subsequently, the aquifer parameters were determined both by commercial software and analytical techniques. The results show that the response to pumping of the investigated aquifers is very variable both among the different sites and within the same site. Despite the considerable potential in groundwater yield at the scale of the system, locally the hydraulic parameters and the well yield are very different due to aquifer heterogeneity, linked to connectivity of fracture and conduit network, and local hydrostratigraphy. To assess the operational pumping flow rate of a well in this hydrogeological environment, the study shows that is fundamental, in addition to the determination of the hydraulic parameters of the aquifer, to examine the trend of the drawdown over time which is often more complex than the available theoretical models. The sequential analysis of the drawdown over time thus becomes necessary to extrapolate a prediction of the long-term response to pumping of a well. The obtained prediction can be then updated based on the monitoring of the drawdown in the well and in the aquifer during the first operational phase of the well.

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Snow cover contribution on groundwater recharge in the Gran Sasso carbonate aquifer (Central Italy) during the period 2019-2022

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Abstract

The contribution of the snowpack to the aquifer recharge is relevant to be assessed in order to evaluate groundwater availability in mountainous karst regions. Despite its relevance, direct measurement and modeling of snowpack effects on aquifer recharge remain challenging due to the limitations of monitoring. Considering a previous study on the Gran Sasso ridge aquifer (1), to validate and quantify the coverage and persistence of the snowpack over time through an objective method, Sentinel-2 satellite images over the period 2019-2022 have been analysed. It has been revealed that Campo Imperatore, the endorheic basin acting as a preferential recharge area of the aquifer, plays an important role, both for hosting the snow coverage and consequently for the infiltration and recharge of springs due to snow melting. The extension of snow coverage out of this plain has a minor influence on recharge, highlighting that the main drivers for infiltration rate are fractured networks and karstic forms more than snow coverage on carbonate outcrops. Indeed, recharge from snow melting in 2019-20, when the snow coverage did not exceed the plain boundaries, has been quantified in about 15% of the total aquifer recharge, confirming what has been previously assessed. Conversely, in both winter semesters of 2021 and 2022, the snow coverage frequently exceeded the basin limits, but the recalculated recharge shows how the infiltration from snow melting located out of Campo Imperatore is very limited, leading to an updated evaluation of snow recharge lower than the one previously assessed (up to -60%). The groundwater stable isotopes have been used to confirm the significant role of Campo Imperatore in the aquifer recharge. Specifically, the assessment of Computed Isotope Recharge Elevation (CIRE) based on the values and oscillations of the $\delta^1 O$ isotope recorded at the main springs, confirmed a recharge directly coming from the Campo Imperatore plain. Indeed, the springs located on the northern slope of the Gran Sasso ridge show similar and steady values of $\delta 18O$ (average -10.5‰) and are characterised by a CIRE ranging from 1600 m asl to 1900 m asl, clearly corresponding to recharge coming from the same elevations of Campo Imperatore endorheic basin. These main findings confirm the high infiltration rate of Campo Imperatore plain and the direct influence of snow contribution to aquifer recharge, whose distribution is correlated with altitude and karst landscape occurrence. In future scenarios influenced by climate change effects, the accurate knowledge of recharge due to snow cover, both in

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terms of preferential infiltration areas and extension, is a primary goal for ensuring a reliable renewable water resource evaluation. (1) Lorenzi et al. (2022) J. Hydrol. Reg. Stud 41:101090

Springs in platform and orogenic karst – A comparative analysis of Floridan (USA) and Dinaric aquifers (former Yugoslavia)

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Abstract

Working on an international project MIKAS ("Most Important Karst Aquifers' Springs" in the world) launched by Karst Commission (KC) of the International Association of Hydrogeologists (IAH) the authors found it interesting to compare two of the globally most productive karst aquifers – Floridan aquifer of the United States and Dinaric karst aquifer of former Yugoslavia. Although both aquifers have similar extent, contain large number of first-magnitude springs, and have some similarities in recharge and discharge regimes, there also are notable differences, the result of their different origin.
Floridan aquifer underlies an area of about 250,000 km2 in southern Alabama, southeastern Georgia, southern South Carolina, and all of Florida. Roughly 20% of the aquifer's extent is unconfined where it is exposed at the land surface, and similar percentage is covered by permeable thin soil or unconsolidated recent deposits which allow active recharge. Similarly, former Yugoslavia (nowadays states of Slovenia, Croatia, Bosnia & Herzegovina, Serbia, Montenegro, and North Macedonia) extends over 255,000 km2, where Dinaric karst and much smaller outcrops of Alpine and Carpathian karst cover nearly 40% of the territory.

The Floridan limestone karst is of platform type, and although well fractured with massive networks of large cavities it was not subject to intensive orogenic movements, compression and folding, as was the case with the Dinaric karst. While depth to groundwater in Florida is quite shallow, usually up to a few tens of meters, in parts of the Dinaric karst the depth of permanently saturated zone can be more than 1000 meters in mountain ranges.

Both aquifer systems are characterized by dominant recharge from precipitation and locally by percolation of water from sinking streams. Annual average rainfall is quite similar, in the range of 1200-2000 mm, but more effective recharge is taking place in Florida due to shallower water table and flat terrains. The springs' discharge monitoring in both regions is far from perfect. Apart from lack of data for some important springs, this analysis uncovered various inconsistencies in literature data, including erroneous classification of the magnitude of some well-known springs.

Florida has quite a few first-magnitude springs (average flow larger than 100 ft3/s or 2.83 m3/s), with different literature sources naming anywhere between 11 and 33 such springs. In Dinaric karst of former Yugoslavia there are 19 first-magnitude springs, with the annual

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variation of their discharge rates much larger than of the Florida springs.

The Floridan aquifer system provides potable water for numerous small and several large cities, including Jacksonville, Tallahassee, Orlando, and St. Petersburg to name a few. Most of the extracted groundwater is utilized for irrigation, public supply, and industry. Some estimates are that average pumping of the Floridan Aquifer via countless extraction wells is 175 m3/s. This is the main factor contributing to the alarming ongoing reduction of springs' discharge. In contrast, Dinaric karst aquifer system is less exposed to intensive extraction, even though three capital cities (Sarajevo, Podgorica, Skopje) and all towns along the Adriatic Coast depend on potable water supply from the karst aquifer.

Keywords: Karst spring, Floridan aquifer, Dinaric karst, Aquifer protection

TOPIC 2
Vulnerability and protection of karst groundwater
POSTERS

Case Study: Assessing Vulnerability and Remediation Strategies in Karst using the DPSIR - "Bolje Sestre" Spring, Montenegro

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Abstract

The sublacustrine spring "Bolje Sestre" (one of many within the Malo Blato (Small Mud)), managed by the Regional Water Work Utility, is positioned on the edge of Skadar Lake. It is a primary water source for the Montenegrin Coast and facilitates the growth of tourism in Montenegro.

Located approximately 30 kilometers from Podgorica in the Zeta-Skadar Valley, Skadar Lake is the largest freshwater area in Southeastern Europe. It spans 370 square kilometers and encompasses various spatial units, including Malo Blato (Small Mud).

Karst springs on the eastern edge of the Malo Blato, especially the source of Bolje Sestre, may receive water through underground connections from other watersheds, including the alluvial sediments of the Morača and Cijevna rivers in the Grbavci Plain.

In contrast to the coastal aquifers, facing challenges posed by over-abstraction and saltwater intrusion, the Karstic Spring Bolje Sestre boasts exceptional water quality, obviating the need for extensive treatment. However, a concerning trend emerges, revealing a significant reduction in its discharge.

Unfortunately, since 2010, dredging activities extracting gravel and sand from the Morača River bed have impacted Bolje Sestre spring discharge, underscoring the direct link between anthropogenic activities in the Morača River and the depletion of this primary water source.

Malo Blato emerges as a potential supplementary water source. However, utilizing this resource necessitates water treatment, incurring additional costs. A logical question arises regarding whether the Regional Water Utility should bear these costs, particularly if gravel excavation is identified as the primary cause of the reduced discharge.

The enforcement of Integrated Ecosystem Management involving decision-makers, alongside the proposal of remediation measures (implementation of the Sanitary Protection Zones with the sediment management and groundwater monitoring protocols and program), will form the foundation for Bolje Sestre spring protection and its continued sustainable use.

DPSIR (Driving forces, Pressures, States, Impacts, and Responses) based Programme of Measures (PoM) proposed for the Bolje Sestre Spring and Malo Blato watershed is essential

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in ensuring sustainable water management, protecting water quality, and mitigating potential environmental impacts. DPSIR involves a multidisciplinary approach that will provide a comprehensive understanding of the dynamics within the karst system of Bolje Sestre, aiding in developing effective conservation and management strategies.

Keywords: Groundwater protection, karst, ecosystem management, monitoring, DPSIR

Determining the spring protection zone:a case study, Sarcheshmeh Spring, Mahallat, Iran

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Abstract

Determining the spring protection zone:a case study, Sarcheshmeh Spring, Mahallat, Iran
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Introduction

Almost the entire economy, agriculture and drinking of Mahallat city is based on the Sarcheshmeh karst spring. So, it is very important to identify the protection zone of this spring and protect it quantitatively and qualitatively.

A: Physicochemical variations

The electrical conductivity variations in the spring water during the year were small (between 390 and 435 micromhos/cm). which indicates the high extent and volume of the aquifer and/or fractured rocks and the diffuse flow in the aquifer. The coefficient of variation of the spring discharge during the measurement period is 8.08%, which indicates a slight variation of the spring discharge, while the coefficient of variation of the electrical conductivity of the spring is 2.8%.

B: Inverse modeling (PHREEQC)

According to the inverse modeling, it can be said that after entering the limestone, rainwater dissolves 0.0575 mmol/kg of dolomite mineral, 0.0256 mmol/kg of gypsum mineral, and 0.004 mmol/kg of Sylvite mineral, and 1.01 mmol/kg sodium bicarbonate mineral is produced.

C: Hydrograph

The monthly rainfall and flow data shows that during the period, the graph had a downward trend.

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D: Time series

The correlogram (discharge versus rainfall) was drawn using SPSS 16.0 software. According to this diagram, the highest correlation value is 5, therefore, the lag time of spring response to rainfall is estimated to be 4-6 months.

E: Isotope studies

Spring samples was sampled for the analysis of oxygen-18 and deuterium isotopes. The comparison of the results with the local meteoric water line (LMWL) shows that the type of recharge in low elevations is diffuse, and in higher elevations point recharge is dominant.

Determining the protection zone of the spring

In order to determine the protection zone of the spring, the average discharge of the spring (105 L/s), the average rainfall of the area (313 mm/y), the average recharge elevation (about 2000 meters) and the infiltration rate (35%) were obtained and the area It was estimated that it can provide water for the spring (about 30.2 km2). Then, by using this number and examining the geological evidence of the area, including the border of limestone with impermeable formations and faults in the area, the boundaries of the catchment zone of the spring were determined. In this case, the area considered for the water catchment area of the spring will be about 27.6 square kilometers, which will have a suitable match with the area obtained from the water balance of the spring. In other words, any kind of water withdrawal in the form of drilling a well in this area will have an effect on the Sarcheshmeh Spring discharge. On the other hand, digging in this area, for example tunneling, can also have a destructive effect on the outflow of water or changing the dominant flow paths. In addition, in the specified area, the construction of any polluting industries, wastewater disposal through absorption wells, garbage accumulation and similar cases should be prevented.

Keywords: protection zone, Isotope, physicochemical variations, Inverse modeling, Time series

Dynamics of Microbial Biofilms in Response to Contamination in Karstic Systems: A Case Study in the Bauges Massif (French Alps)

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Abstract

Our study aimed to quantify the response of microbial communities to hydrological regimes and associated contaminations in a karstic system in the Alps (Bauges massif). It was expected to observe changes in the structure of communities within the karstic system based on seasonal variations associated with the hydrological cycle and human activities in the catchment (touristic activities in winter and agriculture activities in summer). Artificial substrates (clay beads) have been incubated at three stations in the Bauges massif: one station receiving water from an agricultural area, another station contaminated with hydrocarbons and one control station with low contamination. These artificial substrates have been collected every 2 months over a hydrological year (18 months). Microbiological parameters (biomass and activities) were measured on incubated clay beads and were compared among stations to assess the influence of contaminations, and within stations to evaluate seasonal changes in microbial compartment during a hydrological cycle. In parallel, water samples were collected to characterize seasonal changes in physico-chemistry (concentrations of nitrate, ammonium, phosphate, and dissolved organic carbon). The whole dataset allowed to assess the links between hydrology, physico-chemistry, and microbiology in karstic systems. Our results showed differences in the development of microbial biofilms depending on nutrient concentrations measured in stations. In the most contaminated stations, temporal variations in biomass and activity were observed, which may be linked to the influence of hydrology on microbial dynamics in karsts.

Keywords: Karstic System, Bauges Massif, Microbial biofilm, Contamination, Hydrology, Biomonitoring, Water quality

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Element of a pluri-disciplinary project on karstic reservoir characterization : groundwater modelling of the Dévoluy Massif, France.

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Abstract

Dévoluy is a mountain range located in the southern French Alps. It is the last foreland chain before the outer crystalline Pelvoux massif. The carbonate rocks that constitute it form a reservoir of several hundred meters thick, folded and fractured by Alpine orogeny during the Cenozoic. This reservoir, exposed to erosion, was then intensively karstified, creating a network of interconnected karstic conduits leading to a unique outlet: the Gillardes spring. This is one of the most important karstic resurgences in south-eastern France, with a peak discharge that can reach 40m3/s and an average of 5m3/s.

Due to its position in the Southern Alps, a geographical area subject to increasing water stress in the context of climate change, the Dévoluy massif presents a major challenge in understanding and preserving the local groundwater reserves. It is located in an area where anthropic needs a represented by two main activities : agriculture and tourism with ski resort. It is essential to better constrain the underground water resources to protect it from potential pollution and to use it in a sustainable way.

The aim of this study is to provide an overall analysis of the evolution of the karstic reservoir, from its formation to its current state, by analysing each of its components. This section of the study focuses on modelling the dynamic of the karstic reservoir.

The data used are the discharge measured at the outlet and the weather conditions: temperature and precipitation from various stations located in and around the massif. The impact of snow is also taken into account, as the case study is located in a mountainous area.

The model enables us to understand how the different compartments of the reservoir can affect the flow at the outlet and is a way of better understanding the structure of the karstic

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[*]Speaker

reservoir: is there one or more compartments, how do they interact with each other, what is the response of the aquifer to precipitations.

This model can then be used to predict future flow in different scenarios based on climate change projections. These scenarios make it possible to test hypotheses on changes in precipitation and temperature in order to assess the impact of these changes on the behaviour of the reservoir.

Exploration for Submarine Springs using an AUV

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Abstract

Submarine groundwater discharge (SGD) is a significant mechanism for contaminant transport from terrestrial to marine and estuarine environments. Nutrient and contaminant loads carried by groundwater contribute to the eutrophication and contamination of marine and nearshore waters and, unlike contributions from surface water flows, are often unrecognized and rarely quantified. Even in karst aquifers where SGD is from discrete spring vents (submarine springs), little is known in most coastal groundwater basins about the location or magnitude of SGD.

Submarine springs have become targets for groundwater explorationist trying to identify as yet untapped sources of freshwater to supply ever growing coastal populations. Even where it will not be developed explicitly though, the identification and quantification of SGD from submarine springs is needed to develop reliable models of groundwater flow and impacts to groundwater resources in coastal karstic groundwater basins. In that regard, understanding the spatial distribution of SGD is as important as quantifying total terrestrial spring flows. In the summer of 2021, we used an automated underwater vehicle (AUV) equipped with water chemistry sensors (CTD, pH, DO, and turbidity) and high-resolution side scan and multibeam scanners to identify submarine springs in the Adriatic Sea off the coast of Croatia. The AUV allowed us to survey areas as large as 100,000 m2 along transects spaced between 10 and 20 meters apart and at less than three meters from the bottom. The onboard multibeam and side-scan sensors allowed us to identify and characterize the locations of the spring vents, which we subsequently confirmed and photographed using SCUBA. Vent depths ranged from approximately 10 to 30 meters below mean sea level. Runs at shallower depths over the same area produced data from which we've developed 3D models of parameter distributions within the water column above and around the spring vents. Results from our work in Croatia demonstrate the viability of our methods, which we plan to replicate to find and characterize submarine springs in the Mediterranean and Black Seas.

Keywords: Submarine Springs, Submarine Groundwater Discharge, SGD, Karst, AUV, Bathymetric Survey

*Speaker

Field evaluation of carbon injection method for in-situ biological denitrification in Karst groundwater using geochemical and metataxonomic analyses

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Abstract

This study focuses on the bioremediation of nitrate-contaminated karst groundwater, which has become a significant environmental problem due to the increasing usage of fertilizers and sewage disposal. This study aimed to evaluate biological denitrification through carbon source injection in a pilot-scale treatment system. This research provides fundamental information for decision-makers in groundwater quality protection and management and could utilize these assessment guidelines to inform their decisions. The nitrate reduction efficiencies of biological denitrification by injection of carbon source in a pilot-scale treatment system setup were investigated at a groundwater contamination site.The study site for field experiments was located in Pyeongchang (Gangwon-do, Korea) in an area with agricultural activity. The geological composition of the site consists predominantly of biotite granite. The characterization of the field site and determination of groundwater quality, groundwater level, and hydraulic conductivity were performed. The field-optimized carbon injection source was determined using the results from batch tests. Nitrate-contaminated groundwater was obtained from the Pyeongchang study site. The batch test results indicated that sodium acetate showed the highest microbial growth in Pyeongchang groundwater. The calculation of acetate injection dose and ratio (Dacetate = 87.8 g) was calculated by applying a C/N ratio of 2.1:1, which was followed by a previous study.The field test was conducted using acetate as a carbon source for 22 days to assess the nitrate reduction efficiencies of *in-situ* treatment. Geochemical parameters and microbial community analysis using next-generation sequencing were performed before and after carbon source injection. After 12 h of reaction time, nitrate concentration decreased from 31.6 to 4.2 mg-N/L at PC-2, and then remained stable at 3.9 mg-N/L. The nitrate reduction rate when acetate was injected was 29.0 mg-N/L/day. *Aquabacterium commune, pseudomonas brassicacearum, dechloromonas denitrificans,* and *Massilia FAOS*were dominant species after acetate injection. The predictive metabolic pathway analysis returned a total of 374 metabolic pathways, and among them, 246 metabolic pathways had a pvalue less than 0.05, and 67 of them less than 0.0001. Among the differentially observed 246 metabolic pathways, 8 pathways having direct reference to denitrification and acetate utilization were selectively discerned and plotted (Fig. 4), focusing on the denitrification pathways rather than the acetate utilization pathways. Two nitrate reduction pathways of 'DENITRIFICATION-PWY' (nitrate reduction) and 'PWY490-3' (assimilatory nitrate reduction to ammonium) were predicted. Low temperatures are favored by denitrifying bacteria while high temperatures are favored by bacteria that possess DNRA pathway, which involves the uptake of NO3 – , its reduction to NH3, and its incorporation into bacteria. Predictive metabolic pathway analysis indicated that

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nitrate reduction metabolisms during injection of acetate were denitrification and assimilatory nitrate reduction to ammonium. The evaluated hazard quotient of nitrate-contaminated groundwater significantly decreased after acetate injection (non-carcinogenic risk decreased from 1.176 to 0.134 for children). This research could provide fundamental information for decision-makers in nitrate-contaminated karst groundwater quality protection and management. This research could also be used as an assessment guideline for decision-makers in groundwater quality protection and management in active denitrification involving denitrifying microorganisms.

Keywords: Nitrate, Denitrification, Field evaluation, Microbial community, Human risk assessment, karst groundwater

Geological constraints at the origin of karst springs in the Ischitella-Vico territory (Gargano Promontory, Apulia, Italy)

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Abstract

In contrast to the main aquifers in Apulia Region of SE Italy, comprehensive data on minor aquifers (covering approximately 21 km2) in the northern region of the Gargano Promontory remain limited. Spanning the municipalities of Ischitella, Vico del Gargano, and Rodi Garganico, this area features a unique geological and stratigraphic configuration, giving rise to a suspended unconfined aquifer situated at altitudes ranging from 400 to 35 meters above sea level (asl) and, consequently, completely isolated from any contact with seawater.
These geological characters stem from the superposition of permeable rock layers over an impermeable unit, deposited during the Cretaceous period (Aptian p.p. to Santonian p.p.) within a deep-water context. The permeable rocks, specifically the Monte S. Angelo Limestones (MSA) and Monte Acuto Limestones (ACU), exhibit fracturing and are interested by karstification processes. These stratigraphic units, predominantly deposited as gravity flows in a base-of-slope setting (comprising breccia and calciturbidites intercalated with pelagic intervals), covers unconformably the basinal pelagic limestones of the Marne a Fucoidi Formation (FUC). Notably, the MSA, characterized by numerous caves, occasional sinkholes, and some dolines, are particularly susceptible to karstification with respect to the above ACU, that present a main permeability due to fractures.

Structurally, the stratigraphic units form a gentle monocline dipping toward the northwest, featuring small-amplitude folds. Subsequent emersion and erosion phases along the primary valleys have created favourable conditions for the emergence of 26 natural springs along the boundary between the permeable and impermeable units. Discharge from these springs varies, ranging from less than 1 l/s to 34 l/s for the largest (Canneto spring).
In the present contribution we will present a description (based upon detailed geological mapping at a scale of 1:5,000 and geological cross-sections) of the stratigraphic, lithological, and structural features of the Ischitella-Vico aquifer, aimed at performing a classification of the springs based upon the geological setting of each single water emergence. Namely, flow type and pressure in the aquifer body will be taken into account, together with the barrier position and typology. Most of the springs seems to outflow as hanging springs due to presence of perched aquifers, or as overflowing springs related to contact among stratigraphic unit with different type and/or degree of permeability. Eventually, the main chemo-physical parameters of the springs will be presented in order to define the hydrogeological characters of the area, as a first step in the definition of the karst hydrogeology of this interesting sector of the Gargano Promontory.

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Hydrochemical and hydrodynamic regime of the thermometallic karst springs of Voskina, Agiasma and Kyllini in Greece

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Abstract

Karst aquifers constitute one of the main sources of fresh water in Greece. Usually, karst aquifer discharges from a spring. In some cases, the karst aquifer water is mixed with deeper geothermal fluids discharging thermometallic water. In Greece, many karst springs are influenced by geothermal fluids. The deep geothermal fluids flow towards fault zones, mixed with fresh groundwater from the upper karst aquifers and form thermometallic karst springs. The hydrodynamic of such springs is variable and dependent from the precipitation patterns influencing the quality of spring water. Within this study we focus on three thermometallic karst springs in Greece aiming to determine the discharge mechanism of the springs. The springs of Voskina, Agiasma are located in North Greece, while the Kyllini spring is located in South Greece. In all sites, the climatological, hydrogeological, and hydrogeochemical factors were analysed. Additionally, in the springs in North Greece the following field measurements were obtained for three years twice per month: a) spring discharge, b) temperature, c) pH, and d) electric conductivity. The results reveal that the maximum recorded discharge of Voskina was 19 m3/h and for Agiasma was 1 m3/h. The mean water temperature of Voskina and Agiasma was 21 C and 20 C, respectively. In addition, the mean value of the electrical conductivity of water in Agiasma spring is over 2300 μS/cm, while the pH of the water is characterized as acidic (pH < 7). The Kyllini's spring, the maximum discharge is approximately 40 m3/h, while the pH ranges from 7 to 7.55. The average temperature of water is 26∘C and the electrical conductivity is 4400 μS/cm. Obviously, the spring discharge consists of mixed water between geothermal fluids and fresh karst groundwater. From a geological point of view the springs are characterized as fault springs. This research is the first step for the modeling of all springs and contributes to the integrated management of water resources and the protection of groundwater reserves.

Keywords: thermometallic, Greece, fault spring, discharge mechanism

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Hydrochemical study of the impact of urban activities in the surroundings of the city of Mérida (Yucatán, México)

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Abstract

The city of Merida is in the northwest of the Yucatan peninsula, a region of karstic nature of almost
pure carbonate rocks and evaporites, without rivers or streams, slight topographic elevation, and the
characteristic and touristic cenotes (collapsed dolines intersecting the water table). Population in
Merida has increased from 777,615 in 2010 to 921,771 in 2020. There is no main sewerage system
and most wastewater is disposed via septic tanks. As the aquifer is highly permeable and the soil
cover is thin to non-existent, the vulnerability to contamination is high. Accordingly, a groundwater
monitoring campaign was carried out in July 2023 to research on the aquifer water quality in the city
and surrounding areas. 28 groundwater samples were collected from wells. Hydrochemical results
show an affection on the water quality: Nitrate concentration range was 0.8-76.4 mg/L with a mean
value of 24.6 mg/L. Total organic carbon concentration range was 0.5-34 mg/L with a mean value of
3.2 mg/L. High conductivity, chloride and bromide values reveal the presence of brackish waters in
some monitored wells, even a hundred kilometers away from the coast, which indicates, along with an
observed inverse cation exchange process, a saline intrusion potentially promoted by intense
pumping. Besides, the presence of emerging contaminants potentially deriving from wastewater
from Merida including antibiotics and other pharmaceuticals, drugs of abuse (e.g., cocaine),
fragrances, insect

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repellents, UV filters, among others is investigated, and their origin is elucidated using hydrochemical
and isotopic tools (δ18O, δ2H of the water molecule and δ13C of dissolved inorganic carbon). This
research provides key data to emphasize the urgent need for wastewater treatment in this karstic area.

Keywords: Groundwater pollution, hydrochemistry, isotopes, emerging contaminants

Hydrogeological and geophysical characteristics of main groundwater barriers of the Vis island's karst aquifer (Croatia)

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Abstract

The island of Vis is situated in Dalmatia, Croatia. For decades, since the 1950s, its water supply has originated from the island's karst aquifer, which is mainly composed of karstified Cretaceous limestones and dolomites. In 1954, the water supply started with the Pizdica spring, with an extraction site built for military purposes in case of nuclear war. During the 1960s, 70s, and 80s, the extraction site Korita, composed of (today) five drilled wells was constructed. The island is represented as an anticline, but the main geological feature is the diapir structure in its western part (Komiža town). Compared to carbonate rocks, the volcanic-sedimentary-evaporite complex of the diapir is practically impervious and a barrier to the groundwater flow preventing underground seawater intrusion into the aquifer from its western side. In the south of the aquifer, there are karst poljes. The carbonate rock mass under the poljes is infilled with fine-grained material, which significantly decreases their permeability, forming a groundwater barrier. These geological circumstances are the main reason for the existence of Vis island aquifers and the sustainability of groundwater exploitation during some 70 years of pumping for public water supply. The water supply system uses approximately 40 L/s at maximum, and the main problem is the fact that at the end of summer, when the tourist season is still at its peak, there is practically no precipitation and infiltration. In the last few years, geophysical research has been done with the purpose of mapping these two hydrogeological barriers. The research was performed by electrical resistivity tomography (ERT) applying Wenner-Schlumberger array. The main profile was done in Plisko polje, the biggest karst polje on the island, at the exact position of the landing field of the former airport, constructed by the English army during World War II. The profile length was 1,240 m resulting in 200 m of interpretative depth. Interpretation has proven that the underground is almost impervious to the groundwater flow and that the Quaternary material of polje is several tens of meters thick. A few shorter ERT profiles were done in the poljes area and at the boundary of the volcanic-sedimentary-evaporite complex with the carbonates. The study is still ongoing, and in this way, the hydrogeological features of these barriers will be recognized and interpreted in much more detail than before.

Keywords: island karst aquifer, geophysical research, electrical resistivity tomography, hydrogeological barriers, Croatia

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Microfiber pollution in surface and subterranean aquatic environments: investigations in the Classical Karst Region

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Abstract

Anthropogenic (natural, man-made cellulosic and synthetic) microfiber pollution in karst and subterranean areas is still poorly studied. The Classical Karst Region is a rocky limestone plateau stretching from the NE Italy and the SW Slovenia, rich in protected habitats and species, including different stygobionts, such as the *Proteus anguinus*. To preserve these ecological heritages, different European, national and local laws are present. However, regulations often do not take account of the ecological connections between different habitats. In this preliminary study we collected and investigated several water and submerged sediment samples in surface (springs) and subterranean (caves) aquatic environments of the Italian sector of the Classical Karst Region.

Water and submerged sediment samples were analysed according to the methods described in Balestra et al. (2023) and Balestra & Bellopede (2023). All samples were pre-treated through the application of 30% HO for organic matter removal. Detected microfibres (5-0.1 mm) were counted and characterized by size and color via visual identification under a microscope, with and without UV light, exploiting fluorescence given by additives added in many materials. Spectroscopic analyses were carried out on different microfibres to determine materials typology.

Anthropogenic microfibres were found in all examined water and submered sediment samples with high amounts, especially in sediments, highlighting a possibile accumulation of pollutants over time. Only 10-15% of microfibres were syntetics; most of the analysed fibres were cotton. Most microfibres were smaller than 1 mm and abundances increased with the decrease of the considered size. Most of the microfibres were fluorescent under UV light (> 80%) and have especially blue fluorescence. Fluorescent microfibres were mainly transparent, and non-fluorescent ones were especially black, blue and grey.

Anthropogenic microfibres could threat ecosystems and contaminate water resources. Vulnerable and stygobitic species hosted in these habitats could consume or assimilate microfibers, therefore, potentially negative consequences for subterranean water safety at all the levels, such as ecological functionality, biodiversity distribution, ecosystem services and human

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health should be investigated too.

Our results show the presence of anthropogenic microfibres in all examined aquatic habitats, improving knowledge in micro pollutants water contamination, and providing essential information for future research. Analyses on a greater number of aquatic surface and subterranean habitats should be done to better understand this kind of problem. Microfibre pollution monitoring in karst areas must become a priority for habitat conservation, species protection and water resources management, improving analyses on a larger number of aquatic surface and subterranean environments, and taking into account the ecological connections between different habitats.

Keywords: microplastics, microfibers, karst aquatic environments, caves, springs

multi-proxy approach in the Ouysse Karst System - geochemical and hydrodynamical studies

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Abstract

At the edge of sedimentary basin, both autogenic and allogenic recharge can feed karst systems. In these cases, outlet spring water origins can be difficult to assess which leads to issues in water resource management. To better understand these origins and the variations in the hydrodynamic and geochemistry of the outlets of a large and complex karst aquifer, this study propose a multi-proxy approach.

The approach combines origin and groundwater flow path identification by : (i) geochemistry analysis with major ions and water and nitrate isotopes, (ii) understanding hydrodynamic connections by waterlevel crosscorrelation analysis, and (iii) assessment of respective contributions of the different origins (autogenic and allogenic) in outlet springs by a mixing model based on the combined geochemical and hydrodynamic analyses.

This method is applied on the Ouysse karst system. It is a large watershed ($650km^2$) located in Western France and is exploited for its drinking water resource. The upstream part of the karst aquifer is fed by three main water origins: (i) diffuse infiltration on the karstic limestone bedrock; (ii) sinking streams coming from igneous-metamorphic rocks runoff; (iii) sinking streams fed by highly mineralized evaporite spring. This study shows how this watershed feeds the different outlets with the various origins during different hydrodynamics conditions.

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Preliminary Assessment of Saline Intrusion Using Hydro-chemical Indicators in the Karst Aquifer System of Benghazi Plain, NE, Libya.

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Abstract

Karst aquifers are becoming more significant as a fundamental source of water supply over time. Especially in countries as Libya, with a Mediterranean and semi-arid climate in the north and a hyper-arid climate in the south, groundwater is the only source of water supply. Being entirely a karst region, north-eastern Libya is home to karst landforms and groundwater aquifers. Since the state is strongly interested in reaching detailed information about petroleum systems and the advantages of oil explorations, the majority of studies concentration the fields of sedimentology and stratigraphy. On the other hand, this contribution deals with concerning karst hydrogeology and geomorphology, aim using hydro-chemical indicators to evaluate the current status of coastal karstic aquifers in the Benghazi Plain in terms of saline intrusion. Correlation between hydro-chemical parameters such as EC with Cl–, ratio (Cl–/HCO3–) versus Cl–, Chadha diagram, Gibbs plot, hydrochemical facies evolution (HFE) diagram, and mixing rate (Rmix) equation generated from the analysis of sixteen water samples were used to evaluate the conditions of seawater intrusion process in the target area. Chloride (Cl–) is considered a conservative tracer in this study to assess the mixing rate (Rmix). The correlation between major ions shows a strong effect on saline intrusion in a vast part of the study area, where the water samples class falls between mixing and saline. The HFE diagram shows that four locations in the Benghazi plain are totally impacted by the seawater intrusion, whereas the remaining sites are classified as freshwater with noticeable seawater effects. These results are in agreement with the Gibbs boomerang and Chadha diagram for delineating water sources and facies, respectively. Both these plots show a clear seawater effect in the water samples, except at three locations that are dominated by rock ion exchange with water. The mixing rates in the samples range from low to very high values. This study suggests to carry out more extensive studies using hydro-geochemical models to study the concentration of salts in the upcoming periods while finding alternate methods to raise the rate of fresh water, such as rain harvesting and artificial recharge with wells and dams. The recommendations are based on the values of TDS, correlations among ions, the previously mentioned plots, and the salt mixing rates.

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Resource Vulnerability Assessment of the Karst Aquifers in the Friuli Venezia Giulia Region (NE Italy) using the COP Method

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Abstract

Large springs supplied by carbonate reservoirs exhibiting varying degrees of karstification are particularly abundant throughout Italy. In Friuli Venezia Giulia, a significant portion of the water supply relies on groundwater derived from karst aquifers, which are widely present in this territory (28% over an area of 7,924 km2). These aquifers undergo replenishment through abundant rainfall, which in the pre-Alpine belt reaches the highest European value of 3300 mm/year. Nonetheless, until now, these high-quality water resources have consistently been underutilised, with a prevalent preference for exploiting the water coming from the numerous wells located in the Friulian alluvial plain. However, the gradual qualitative and quantitative depletion of lowland resources, attributed to overexploitation and widespread pollution stemming from escalating anthropic pressure, is currently prompting a heightened focus on the water reserves contained within mountain karst aquifers. These aquifers, owing to both their superior quality and substantial quantities, potentially constitute an indispensable resource for future drinking water supply. Unfortunately, due to the concentrated recharge of water and its rapid infiltration, the high permeability of aquifer systems, the swift transport in karst conduits over large distances, and the limited self-purification capacity of the water, such aquifers are particularly susceptible to contamination and, consequently, must be vigilantly monitored. In pursuit of this objective, and in accordance with specific regional laws, the Geological Survey of Friuli Venezia Giulia initiated a collaboration with the University of Trieste since 2017. The goal was to carry out a multi-year project for developing scientific methods in support of institutional activities, particularly in reference to karst areas and regional karstic aquifers. Within the framework of this agreement, 128 karst aquifers were mapped. 16 of these were studied in detail, and their intrinsic vulnerability was assessed by using a GIS-based protocol known as the COP method. Presently, an additional 8 aquifers are undergoing study. Intrinsic vulnerability hinges on the geological, hydrological, and hydrogeological characteristics of the aquifer, without delving into the specific nature of the pollutant. The vulnerability assessment considers the layers overlying the aquifer (O factor), the concentration of flow (C factor), and the precipitation regime (P factor). Numerical scores are assigned to each factor and combined to establish an index of groundwater vulnerability, ranging from 1 ('Extreme') to 6 ('Very low'). The acquifers investigated show very high vulnerability values, with 87% of their area falling in the 3 upper classes: 'High' (36%), 'Very high' (38%), and 'Extreme' (12%). The greatest vulnerability is found in karstified limestones affected by the highest rainfall and lacking of soil and vegetation cover, and in the areas at the lowest altitudes close to the springs, where the unsaturated

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zone is less thick and the protection drops, as well as in the areas of maximum concentration of flow, where water sinks into the subsoil through sinkholes, karst furrows, caves, and swallow holes. The resource vulnerability maps obtained can be effectively utilised to pinpoint regions within these areas that are more susceptible to pollution risks, thereby necessitating thorough monitoring and protection measures.

Sustainability and resilience in dual alluvial-karst aquifers: Building a groundwater mental model based on desirable future in Western Iran

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Abstract

In today's world, mental models are crucial in advancing sustainable development and resource resilience, particularly for managing depletable and non-renewable extractive resources such as groundwater. Presenting desirable mental models, especially for groundwater management, is a critical social framework for understanding, participating in basic actions, and supporting stakeholders in implementing decision-makers and regional managers' compiled programs. The complexities of vital resources can both deter people from realistic visualization of these resources and motivate a sense of excitement and greater understanding to preserve them. In Western Iran, covered karst aquifers are a significant source of drinking water supply and maintaining the balance of the ecosystem in karst wetlands and springs, but they lack protection or promotion programs for resilience against deep drilling penetrating karst aquifers and unlawful groundwater exploitation. In the western regions of Kermanshah province specifically where there is no public image of karst waters, the mental model of the underground is still the sea. However, in this area, the mixing of karst and alluvial waters has occurred through the deepening of agricultural wells. This suggests that the local people still perceive the underground as a vast body of water similar to an ocean or sea (the mental model), but they are also aware that there are different types or sources of underground water (the thinking of underground water veins). This dual understanding may have developed due to the presence of both karst and alluvial aquifers in the region. In contrast, in the northern plains of Hamadan province, the mental model of the underground is also the sea, but the existence of large caves and sinkholes has reinforced this perception for local people. The discovery of large underground spaces filled with water has further solidified their belief that underground spaces are vast bodies of water similar to oceans or seas (the mental model). This strong mental model may have contributed to an increase in exploitation despite fears of being swallowed (the fear of being swallowed has not been able to influence the decrease in water exploitation). However, there is potential for promotion or protection programs from karst resources to further influence local attitudes towards karst resources (the model can accept promotion or protection programs). The depletion of groundwater levels, coupled with population growth and agricultural dependence, has led to unsustainability in groundwater, causing extreme events such as sinkhole events, land subsidence, degradation of groundwater quality, water scarcity, and social tensions. To address

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this issue, a groundwater mental model has been developed in this article by presenting conceptual models of the status of several karst-alluvial aquifers in Western Iran. This model aims to raise awareness of the importance of karst groundwater protection promote public cooperation to envision a desirable future and suggest basic steps to achieve sustainability or at least distance from unsustainability, expressed through various climatic, socio-economic, and environmental indicators.

Keywords: Mental model, karst, groundwater, sustainability

The influence of multi-year drought periods on the flow regime of the saturated zone of the Karst springs of the Dir of Beni Mellal in Morocco

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Abstract

The Beni Mellal Atlas, a southern extension of the folded Middle Atlas, extending 100 km in a NE-SO direction, is one of the best watered areas in northern Africa. These precipitations feed the piedmonts inscribed in the powerful carbonate formations (limestones and dolomites) of the Lower Lias, an aquifer supplying numerous springs. These sources contribute to the irrigation of the Tadla plain, the 1st irrigated area of Morocco.

The current drought experienced by this sector of Morocco, like almost the entire country, has a considerable impact on the flow of springs since some of them are recording their lowest flow since they were measured, around 50 for some, while Morocco already experienced a lasting drought in the early 1980s.

The subject of this communication is the study of the impact of recent climatic drought on the karst sources of the Dir of Béni Mellal and more particularly on the fraction of the most regular flows of the karst system corresponding to the emptying of the saturated zone. The study is based on monthly data produced for 50 years from around twenty sources. More precisely, it will be necessary to evaluate the modifications implied by periods of lasting drought in the flow regime of the flooded zone, as well as on the speeds of drying up and replenishment of this part of the karst aquifer.

Keywords: Drought, karst spring, saturated zone, recession, Morocco.

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The Real-Time Monitoring Technology of Karst Groundwater and its Application in the Prevention of Induced Karst Collapse

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Abstract

Since 2020, there have been four karst collapse incidents in Longgang District, Shenzhen, China, causing subsidence and cracking of residential buildings and streets, affecting the safety of residents and vehicles. This article mainly introduces the achievements of emergency exploration.

1.This area is a covered karst area, with the upper 5-11 meters of the Quaternary soil layer being a silty clay layer, and the lower 1.2-17 meters being a gravel layer. The underlying strata are the limestone of the Lower Carboniferous Shitanzi Formation, which was formed 355 million years ago. The bedrock surface fluctuates greatly, and karst caves and fractures are developed. As confined aquifer, the depth of karst water piezometric level is about 5-8 meters; Usually considered as a high-risk area for karst collapse.

2. There are 3 construction sites within a radius of 1 kilometer from the collapse, including one TBM construction for subway tunnels and two excavation of deep foundation pits for skyscrapers. The collapse is likely induced by these engineering activities.

3.In order to confirm the triggering factors of collapse, 7 boreholes were selected as monitoring holes, and piezometers and dataloggers were installed to monitor changes in karst groundwater level, with a monitoring frequency of 12 times per hour. All monitoring data is automatically transmitted and can be directly browsed through the APP. The results indicate that there is a close relationship between changes in karst water level and engineering construction, which has become direct evidence of karst collapse induced by engineering construction.

4. It can be seen that the risk of induced collapse can be reduced by monitoring and guiding construction optimization methods. When the monitoring shows abnormal changes in the karst water level, such as a sudden drop, the construction party should be notified immediately to stop work and optimize the construction process until the monitoring results return to normal. This work continued until the completion of construction, and no new karst collapse occurred. This indicates that karst groundwater monitoring technology can be applied to prevent induced karst collapse.

Keywords: karst collapse, sinkhole, geohazard, karst water management

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Turbidity correction applied to in-situ monitoring of natural fluorescence.

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Abstract

Karst aquifers are vulnerable to contamination due to rapid transfer of infiltrated water. These aquifers are however often recognized as strategic water resources for drinking water, particularly in Mediterranean climatic conditions. In this context, the implementation of monitoring strategies to anticipate as early as possible the transfer of contaminants through the infiltration zone requires a well understanding of their hydrological functioning. Natural organic matter (NOM) has been the subject of numerous studies based on the fluorescence properties of organic compounds, revealing the value of monitoring this proxy as a tracer of karstic flow dynamics through the infiltration zone. According to wavelength, humic-like NOM is an indicator of rapid infiltration dynamics, while proteic-like compounds can in some cases reveal anthropogenic contaminant fluxes. Changes in NOM signals can be very rapid in karst systems, particularly during flood event. Thus, as part of the ANR-funded PEPR Onewater K3 project, this study aims to propose and test different protocols for high-frequency optical monitoring of karst spring or well outflows that could be used to set up an early warning system for water contamination (Frank et al., 2018), specifically designed for karst groundwater.

First results obtained with GGUN fluorometers (Albillia Sàrl) show the importance of correcting fluorescence monitoring for spurious signals due to water turbidity. The aim of this study is to describe the correction method developed by Schnegg (2002), and to test it using standard turbidity solutions. Limitations and improvements to this method are presented, in particular by comparing it with a conventional regression method. These methods are also applied with fluorescence time-series from two monitored karstic springs in southern France: the Lez spring and Fontaine de Nîmes (SNO KARST network observatories), to produce a natural fluorescence time series.

Frank S., Goeppert N., Goldscheider N. (2018). Fluorescence-based multi-parameter approach to characterize dynamics of organic carbon, faecal bacteria and particles at alpine karst springs, Science of The Total Environment, 615.
Schnegg P.A. (2002). An inexpensive field fluorometer for hydrogeological tracer tests with three tracers and turbidity measurement. *Articles of the Geomagnetism Group*, University of Neuchâtel.

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Keywords: NOM, Fluorescence, Turbidity correction

Understanding mass transfer mechanism between karst conduit and matrix: A critical review and meta-analysis

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Abstract

Due to the multiscale heterogeneity - referring to the spatial variations of the aquifer's physical and chemical characteristics at varying scales -, contaminant transport behavior in karst aquifers is described by the different anomalous characteristics such as power-law tailing, high skewness, and multiple peaks in tracer breakthrough curve (BTC). While these anomalies are mainly controlled by the preferential flow paths (i.e., karst conduit, fractures), the rate-limited mass transfer between the karst conduit and neighboring carbonate matrix is one of the critical processes in shaping the long-term transport behavior of the contaminant plume. The mass transfer mechanism between the karst conduit and matrix is often described by a single (first-order) mass transfer coefficient. Nonetheless, the experimental identification and/or proper characterization of this parameter at the domain of interest is rather difficult, and it might not even be possible. For that reason, the mass exchange between karst conduit and overlapping matrix is mostly inferred from the dual domain transport modelling approaches via a set of model calibration. Therefore, the model parameters are likely to be nonunique and mostly uncertain. In this study, to enhance our understanding about the anomalous transport in karst aquifers due to the mass exchange (mostly resulting in the power law tailing in BTC), we critically review the current state of knowledge in the modelling of dual domain transport characteristics in karst aquifers considering the description of the mass exchange coefficient. To do so, we performed a systematic literature review and meta-analysis by applying a guideline called "Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA-M)". Through a meta-analysis of the selected published scientific papers, we synthesize the accumulated knowledge on the mass exchange mechanism between the karst conduit and overlapping carbonate matrix. Our analysis based on the meta-analysis reveals that the mass exchange coefficient is strongly dependent on the (mean) flow velocity along the karst conduit, whereas establishing a statistical relationship between the mass exchange and conduit flow velocity is rather complicated, likely due to the uniqueness of the (mass transfer) parameters for different karst systems. From this point of view, we address the uncertainties in providing model results for the dual-domain transport and mass transfer mechanism between the karst conduit and matrix, as well as the scientific challenges we must face for the description of the transport processes in karst water resources.

Keywords: Karst, contaminant transport, mass transfer, review, meta analysis

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TOPIC 3
Karst geomorphology and landscape
ORAL PRESENTATIONS

A karstic cave with an exceptional geological value: Cueva de las Estegamitas (Málaga, Southern Spain)

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Abstract

Cueva de las Estegamitas (Stegamites Cave) is a karstic cave accidentally discovered in the spring of 2021, by the mining works of a limestone quarry near Málaga (Southern Spain). The cave has a length of approximately 1400 meters, with a maze-like layout. The geomorphological characteristics of the cave, with erosive morphologies linked to a hypogenic origin, and its position, near the Mediterranean coastline, with an elevation of 80 m a.s.l., link the origin to the freshwater-saltwater interface, during a period of high sea level in the Pleistocene. The cave is developed in the Jurassic limestones of Maláguide Complex (internal zone of Betic Range), in a limestone massif that constitutes a small coastal carbonatic aquifer, with a piezometric level near the sea level. The average environmental characteristics of the cave include a temperature of 21∘C, a relative humidity of 91%, a CO_2 concentration of 810 ppm, and a $222Rn$ activity of 1308 Bq/m3. The conservation of the cave is exceptionally good, with the only exception for a few of mineral looting (calcite and aragonite crystals and speleothems), that took place in the initial stages of the discovery. The geologic values of the cave are focused on the exceptional conservation state, the cleanliness of the erosive morphologies that characterize the speleogenesis, the great variety and quantity of speleothems (including numerous eccentrics, *butterflies*, coraloids and others), and specially the presence of a very numerous set of stegamites in all their evolutionary stages, ranging from small fractures in the floor of the cave, from which the stegamites emerge, to some samples with a height of nearly 2 meters. This circumstance has allowed the proposal of an origin and an evolutionary sequence for this particular and rare type of speleothems, initially linked to the presence of a detritic floor covered by a calcitic layer. Later, the fracture of this layer, probably caused by the expansion of the clay minerals existing in the detritic sediments and the presence of water, allowed the migration of small amounts of water through the fractures, upward, using capillary forces and forming the stegamites, with processes of precipitation. Stegamites are characterized by this origin and by their shape, similar to a crescent, or the crest of a stegosaurus, hence their name. Stegamites are considered a very particular type of speleothem, extremely rare and described in few caves in the world in scientific literature. The Stegamites Cave presents some geological characteristics that stand out, and make this cave deserve the highest levels of protection. The fact that is in an active mining site must not be an impediment for the compatibility of the mining activity in the area, and the conservation of the cave. Good practices of the European mining sector, their compromise with

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the environment and the natural heritage must prevail, versus the certain loss of the cave, its content, and the knowledge that the cave could provide.

Keywords: geoheritage, coastal caves, mining, speleothems, stegamites

Earth's critical zone and karst critical zone: structure, characteristic and lower boundary

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Abstract

Critical zone science has become one of the important research areas in surface-Earth system science, representing a future new idea and developing trend in Earth system science. The karst critical zone, a unique type, covers approximately 15.2% of the global ice-free continental land, which is a typical case and represents of the Earth's critical zone. However, there is still a lack of a unified understanding of the scientific connotation of karst critical zone (KCZ), and a lack of related discussions on the structure, characteristics, and lower boundary of the KCZ at present. Based on reviewing the history of the scientific development of the Earth's critical zone and summarizing its main characteristics, this study sorts out the background and development processes of the concept and summarizes the characteristics of the KCZ. The lower boundary of the KCZ, which is still controversial, is analyzed and discussed, and the further development direction of the KCZ is also analyzed. These results showed that the KCZ is a unique type of Earth's critical zone shaped by material circulation and energy flow at the interface of lithosphere, hydrosphere, atmosphere, biosphere as well as pedosphere in soluble rock area. The spatial span of the KCZ ranges from the vegetation canopy to the lower boundary of the karst aquifer in the soluble rock area, including the vegetation layer, soil layer, epikarst, vadose zone, and saturated zone, which are sensitive to environmental changes and have surface and subsurface double geological structure, special geochemical processes characterized by coupling cycles of carbon, water, and calcium. By comparison, the KCZ has the eight following characteristics: active involvement of carbonate rock in the material cycle, sensitive response to external environmental changes, multilayers hydrogeological structures, strong horizontal spatial heterogeneity, large underground space network, large-span biota structure, unique ecohydrological processes with carbonate rock-water-vegetation interaction as well as varying lateral boundary controlled by subsurface divide change. The lower boundary of the KCZ is the depth at which the groundwater recharged by precipitation has no influence on the dissolution of carbonate minerals (calcite, dolomite, etc.) and also has no ability to further dissolve carbonate minerals (calcite, dolomite, etc.) in a certain range below the surface. According to the development trend of the disciplines and national strategic demands, further attention should be paid to the following four directions: the structure, formation, and evolution mechanisms of different types of the KCZ, the ecological service function, and regional sustainable development in degraded karst ecological zones, the impacts of engineering activities on the structure, attributes, and evolution process of the KCZ, and the coupling process between climate change and the change of structure, function and attributes of the KCZ.

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Evolution of the karst network from surface to subsurface within fault zone

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Abstract

Karstic aquifers are highly reactive and heterogeneous hydrosystems, characterized by a strong interaction between surface water and groundwater. In the Mediterranean area, rapid recharge occurs in active losses located along temporary rivers, enabling a swift flow to infiltrate deep into the groundwater reservoir. However, this recharge can also occur more diffusely, with rain flowing over rock outcrops. These features make karst aquifers vulnerable to climate change: diffuse recharge appears to decrease with increasing temperatures, while rapid recharge is favored by the intensification of extreme events, particularly presents in the mediterranean area. The karst structures, often developed on tectonic features, enhance these concentrated rapid recharge areas, providing crucial replenishment for societal and agricultural needs. Improving our understanding of these concentrated recharge zones is important for preserving the present water quality at these vulnerable points and to characterizing the future quantitative flow of this recharge.

The existence of losses associated with the karst network near fault zones sparks interest in understanding of the relationship between these fault zones and the karstification process. This study focuses on exploring the connections between fault zone architecture and karstification in proximity. It entails a comprehensive morphological and geological description of these elements, emphasizing the geomorphological characterization within these loss zones. This approach enhances anticipation, exploration, and comprehension of surface-to-underground transfer dynamics. Our research employs a multi-scale approach to characterize surface geological structures, involving high-resolution structural mapping through LIDAR-equipped drones and numerical analysis of fault zone fracturing using aerial orthophotographs. Geological investigations, field observations, and tectonic analyses in karstic cavities, further explore the link between surface features and subsurface structures.

The comparison between subterranean and surface dual photogrammetry represents a novel approach, providing insights into the development of karstification from the surface to depth. It helps establish the spatial evolution of active loss zones, bridging the understanding between surface and subsurface dynamics in karst evolution.

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This study concentrates on the Lez spring catchment area, supplying water to Montpellier in southern France. This region constitutes a complex karstic system intersected by major faults significantly influencing the reservoir's structure. Multiple loss zones along these faults contribute to aquifer dynamics, particularly evident along the Corconne-Matelles fault, indicating rapid transfers facilitated by the karstic network at specific karstic loss points within the fault zone.

Our research establishes connections between observed tectonic and karstic surface structures, emphasizing the critical role of fault zones in shaping the surrounding karstic network. It highlights specific fracture families' significant influence on fracture dissolution, applying substantial structural control over the karstic network. Furthermore, it identifies diverse fracture families and their distinct roles in the development of karstification, impacting the water transfer dynamics within this environment. Examining the morphology of these loss zones within karstic aquifers at fault locations aids in identifying analogous areas, facilitating the creation of a map outlining vulnerable zones within the aquifer system and aiming to establish mechanisms to promote recharge at these points.

Keywords: Karst, Carbonate, Lez aquifer, Fault zone, Geomorphology, Geological structures, Multiscale

Expressing karst hydrogeology through choral music - the conception and realization of Inception Horizon

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Abstract

Inception Horizon is a choral piece of music that was created as a unique collaboration between scientists / engineers and artists to increase public perception and understanding about the fascinating subterranean karst network beneath the ground, as well as providing a stimulating artistic experience. More specifically the work was composed to bring the listener on the journey of water through a karst network, from the time when rain droplets first enter the ground, via percolation through the vadose zone before joining conduit flow brings it to its final re-emergence at a spring. The work, composed for 6 choral parts, expresses constrained laminar flow before moving into more free turbulent flow with the growth in volume and the convergence of the network en route. It also captures the stillness of the open cave at more stagnant points and culminates in the water's rebirth in the form of a spring at a lower level. The rhythms and pacing follow the journey of the water and the natural flow of the text which has been taken from the karst lexicon and several passages from academic texts. The work was first performed as part of a wider creative public engagement experience on karst in 2020 in Trinity College Dublin which took the audience on a journey deep underground, following the flow of water through song, sculpture, visual projections and spoken word. The film was then made based upon the music, which was a finalist at the UNESCO Earth Futures Festival 2022, ranked third in the Peoples Popular Choice. The choir then travelled to Slovenia in September 2022 to perform the choral work at Županova jama (cave) in collaboration with the Slovenian Karst Research Institute. This paper charts the journey of this piece of music from its initial conception through to the performance in the classic karst of Slovenia.

Keywords: karst hydrology, choral, music, public engagement

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GIS-based morphometric study to genetically characterize dolines in the SE sector of the Classical Karst Region (NE Italy)

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Abstract

Starting from October 2022, in collaboration with ISPRA (Italian Institute for Environmental Protection and Research) and the Geological Survey of the Friuli Venezia Giulia Region, activities have been launched for the creation of the Sheet 110-131 "Trieste-Caresana" of the Italian Geomorphological Map as part of the CARG project. The territory to be mapped includes a section of the Italian part of the Classical Karst Region, the one limited by the village of Aurisina (NW) and the Rosandra Valley (SE). The Karst area is globally renowned for its pronounced expression of the karst processes and the wide variety of landforms. For these reasons it has represented the cradle of karst studies since the end of the 17th century.

In the Classical Karst area, dolines are probably the most distinctive landforms, being widespread and characterized by significant variety in shapes and sizes. One of the main challenges related to characterization of dolines in a mature karst context is the difficulty in determining their genetic process with a defined, large-scale applicable criterion. The dissolution process can, over time, conceal markers that allow to clearly distinguish on the field a doline formed by the collapse of a cavity from one generated by the solution of bedrock. A morphometric approach is proposed to classify dolines in an intensely karstified area on the basis of the predominant genetic process (collapse or solution), using slope steepness as the main parameter.

The carrying out of the remote sensing and field surveying activities, as part of CARG project, has facilitated the collection of a substantial amount of new data on epigean landforms. Specifically, a new high-resolution (0.5 meters) Digital Elevation Model has enabled a more accurate delineation of these features for morphometric analyses. All karst depressions and their bottoms were digitized through remote sensing starting from the homogenization of existing data and with the support of field surveys. A total of more than 7,000 dolines have been identified in a total surface area of 115 km2.

Information regarding the edges and bottoms of the dolines have been processed using the GIS zonal statistics tool. The areas related to the slopes of the dolines have been extrapolated and then parameterized according to their steepness. This methodology has allowed for the formulation of a preliminary genetic model for dolines in the study area.

To validate this model, a sample of dolines with clearly defined genesis has been selected. Geophysical investigations, as well as a borehole, have been planned to verify the GIS-based procedure. The geological context has been also considered, paying particular attention to the dip of the strata.

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On the risk of desertification in karstlands

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Abstract

Nowadays, desertification is a serious environmental problem in terms of economic losses and social issues, and represents a major risk especially in drylands, that are characterized by negative water balance and scarce presence of soils. A considerable percentage of the global karst areas is found in drylands. Karst environments are characterized by peculiar hydrology and hydrogeology, with a high physical anisotropy due to presence of fractures and large conduits within the rock masses, as well as a direct relationship between surface and subsurface environments. For these reasons, karst results particularly sensitive to a variety of anthropogenic actions that may have severe impacts on the pristine environment, making very complex, highly time consuming and expensive the restoration practices. In karst, desertification is one of the main threats and represents the result of climate change effects and of unsustainable anthropogenic activities over the years, which are causing the gradual loss of karst natural resources such as soil, vegetation, and groundwater. Karst desertification is due to four main factors, all mostly or in part related to human activity: deforestation, improper land uses, groundwater overexploitation and climate changes.The work provides an interesting overview of the processes potentially leading to a risk of desertification in karst environments. An overall description of karst settings is provided, aimed at pointing out the fragility of such an environment and the importance of the natural resources therein contained (first and foremost, groundwater). Then, considerations about how, and at what intensity, desertification processes act in karst areas will be presented. Eventually, in the conclusion some open perspective for future research will be listed, also providing indication for the best monitoring methods to apply in karst areas at risk of desertification and emphasizing the importance and the need to preserve these fragile environments, characterized by peculiar features and precious freshwater resources.

Keywords: Karst, Desertification, Land degradation, Human impacts, Climate change

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SINKHOLE'S SETBACK DISTANCES: THE METHODOLOGICAL APPROACH APPLIED TO THE EVAPORITIC ENVIRONMENT

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Abstract

Sinkhole hazard has been definitely a highly underrated type of disaster all over the world and not less in Italy even if the occurrence of these phenomena can cause serious damages to infrastructures, economic activities, and human health. Nowadays it is more common to read on the newspapers or to see on tv news about the occurrence of this type of phenomena in urban environment than in natural context as for example in Naples or Rome, where the cities have been built over the ruins of ancient civilisations. This doesn't mean that natural sinkholes do not occur, but that the phenomena affecting urbanized areas are more newsworthy due to the damages they can cause.

One example is given by the sinkholes affecting the municipalities of Enemonzo and Ovaro (NE Italy), where, since 1960s, human-made structures are dealing with collapses and on-going suffosions. Surely having a dynamic database collecting the information regarding these types of phenomena is fundamental in all the territorial planning activities, but also having setback distances which could help in understanding the evolution of these phenomena is important. Extensive survey campaigns during the last 10 years, made it possible to identify 1435 sinkholes and characterize them from a morphometric point of view.

In light of the above-mentioned thoughts, a new methodological approach is here proposed to those natural phenomena linked to the presence of the evaporites in the subsoil. The latter lithology is characterised by a fast dissolution rate with a consequent rapid occurrence and evolution of the former sinkhole features. What is done for the evaporites, is not applicable to the carbonates, which present much more conservative morphologies. This implies more site-specific analysis and the application of an automatic approach is not recommended. The method for defining the setback distances in evaporitic environments, is based primarily on the collected data characterising every single phenomenon such as type, state of activity and involved material. Starting from geotechnical data, a trigonometric formula whose factors are the minor and major axes, the depth and the equilibrium angle allows to calculate a buffer around each feature in order to outline a safeguard area. Once the setback distances are defined in terms of geometry, a specific hazard is assigned following what initially proposed by the national P.A.I. Project (Piano di Assetto Idrogeologico – Hydrogeological Asset Plan) realised for the landslide phenomena.

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Speleogenetic reconstitution of a karst combining underground and surface geomorphology - implication for hydrology (Verneau, French Jura)

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Abstract

The aim of our work is to propose a speleogenetic reconstitution of a karst network, combining two complementary morphological approaches from underground and surface data, in order to relate the speleogenesis model with the hydrogeological one. The study site is the underground karst network of Verneau (French Jura), which has the particularity of being almost completely penetrable and topographically recognized. The hydrosystem is characterized by 5 sinkholes draining the marly outcrops of the recharge area. First, the geometry of the underground network (orientation and organization of conduits) is characterized using the open-source software Karstnet. Second, a chronology of the network development is assessed by calculating the erosion time required to shape the surface forms of the marly sinkholes watersheds, identifying the erosion levels and estimating the eroded volumes using DTM data. Finally, the spatial variability of the water level dynamics along the conduit network is characterized using a comparative approach of the hydrological response recorded at 6 stations.

The quantitative approach of the geometrical characterization of the underground network allows us to divide the Verneau into two downstream and upstream compartments with significantly different properties on conduit orientation and network organization. On the surface, we traced the erosion levels of each losing stream, then quantified the erosion time required to form the surface shapes. The information gathered is convergent, enabling us to propose a coherent model of speleogenesis of the Verneau underground network through the phases in which the surface network was captured during the Quaternary.

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The study of water level variations at different sites along the network showed that there is a spatial variability of the hydrological response, consistent with the morphological downstream/upstream compartmentalization identified in the speleogenesis model. Moreover, the comparative analysis enables us to date the compartments relatively well, to deduce the structural history of the Verneau network, and to relate it to its current hydrology.

This work represents an initial approach to the development and structuration of karst aquifers in the Jura Mountains.

Keywords: Karst, geomorphology, hydrogeology, speleogenesis, French Jura

Study of the influence of surface hydrological features in the recharge processes of karst aquifers in southern Italy

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Abstract

Karst environments are peculiar settings characterized by small- to large-scale morphological features that typify karst terrains, such as ponors, shafts, dolines, poljes, caves, endorheic basins, etc. These landforms create a deep interaction between groundwater circulation and surface hydrology as they control meteoric water runoff/infiltration, the transferring of water into underground, and thus groundwater recharge.

In this framework, mapping karst landforms, understanding their formation mechanism and hydrological role, combined with the analysis of geological and geomorphological data, are of crucial importance to characterize a karst system. In particular, this information represents the starting point for many investigations, including hydrological modelling of surface runoff and groundwater recharge, delineation of protection zones for wells and springs, simulation of point source contamination, and artificial test planning. This contribute presents the results of a study concerning the mapping of hydrological karst features of the Matese and Alburni massifs (southern Apennine chain), whose relevance is due to the presence of large basal springs supplying millions of people. An accurate GIS-based procedure was applied for a hydrological analysis of high-resolution Digital Elevation Models (DEMs). This analysis is the primary method used in map making for the identification of dolines and poljes, first, and of small- and large-scale endorheic areas, then. In detail, the mapping procedure started from automatic identification of the closed depressions of the DEM surface. In this phase, the location and depth of both false and true depressions were determined. Then, a statistical-based method was used to calibrate a threshold depth with the aim of reducing the number of false depressions. All depressions shallower than 0.55 m were therefore filtered off and a verification of the remaining depressions was carried out by visual inspection of various informative layers (DEM-derived contour maps, hillshade, Google Earth images, and IGM topographic maps). The perimeter of the (true) karst depressions was mapped according to the outermost closed contour method. Endorheic areas, representing the catchment of one or more dolines, were then automatically delineated using a built-in ArcGIS tool, based on information derived from dolines mapping.

Other karst features, including ponors, caves, and karst springs were also mapped based on surveys of Campanian Speleological Federation and on data from the literature. In addition, for Matese karst massif, hydroelectric facilities of the main endorheic areas were mapped. Cartographic data were integrated with information derived from the morphometric analysis

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of karst features, climate analysis, and hydrological modelling of aquifer recharge processes.

Tracer tests, only for Alburni karst massif, allowed to derive a schematic hydrogeological model which illustrates the connections between infiltration areas of superficial water and basal springs.
This study provides new insight into the hydrological karst features of Matese and Alburni carbonate reliefs controlling the infiltration and, thus, groundwater recharge of extreme interest for water resources management and protection.

Keywords: endorheic area, ponor, doline, karst spring, Matese massif, Alburni massif

Surface water - groundwater interaction induced by geomorphology: The Sant Josep karstic system (La Vall d'Uixó, Castellón, Eastern Spain)

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Abstract

The Sant Josep cave, with an approximate length of 3000 meters, is the main cave of a karstic system excavated in Triassic dolostones in the western part of the Sierra del Espadán Natural Park. The cave entry is an important spring (with an average flow of 100-200 L/s), located in La Vall d'Uixó, Castellón (Eastern Spain). Along the cave, an underground river flows, with the last 750 meters before the spring controlled by a dam. This is used for the regulation of the swelling and to visit the cave with small boats with approximately 250.000 visitors yearly. The cave is located near the Belcaire River, in the southeastern area of the Iberic Range, close to its coastal end in the Plana de Castellón. The Belcaire River and the cave are connected, both directly, via small shafts or "*avencs*", in the riverbed, and indirectly, detected by artificial tracers. In the Belcaire valley, there is an average rainfall of 520 mm/year, which occurs in small episodes followed by long periods of draughts, leading to important surface runoff during the rain events, accentuated by the lack of well-developed soil and high grades in the slopes of the valley. These shafts structures are crucial during the rainfall events, as they act as injection points to the karstic aquifer. The geological structure is a series of parallel folds and faults that strike roughly NW-SE and NE-SW. These structures affect mostly the Triassic dolostones *Muschelkalk*, or L'Oronet Formation, where the cave is located. One of the syncline folds conditions the layout and the geomorphology of the cave, with a main meandering gallery and smaller, secondary galleries, located slightly higher, and currently dry, without the presence of the underground river, except during high swellings. This work compiles the geomorphological characterization of the cave and a conceptual model of the karstic system. A set of geomorphological sections has been developed, that represent the processes that take place inside of the cave and the isotopic dating of speleothems. These sections have been used as tools to characterize the interactions between the surface and the underground water. The study of the stable water isotopes (δ18O and δ2H), and the hydrochemical study of a swelling that took place during a rainfall episode of 60 mm that affected the underground river and the spring, are represented in a simple model. The conceptual model presents the hydrochemical evolution in a theoretical flow line along the karstic aquifer, and the sedimentary formations of the Plana de Castellón aquifer, until the water reaches the Mediterranean Sea. Lastly, the intermediate position of the underground river as a main conduit between the surface and the aquifer has been stablished, intercepting this flow line, and acting as a "tunnel" in the vadose zone of the karstic aquifer.

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THE MYTH OF TRIPLE POROSITY KARST AQUIFERS IN ANCIENT CARBONATES

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Abstract

Among the properties of karst aquifers, it is well established that their triple porosity (comprising matrix, fracture and conduit components), is one of the most characteristic, being a key feature that controls flow and storage of groundwater and differentiates karst from other bedrock aquifers. This paradigm is widely accepted, usually without considering the vast variations related to depositional (syngenetic), tectonic, and the later evolution history of carbonates. This concept probably arises from the dominance of karst hydrogeology studies in the Northern Hemisphere, where the triple porosity concept was formulated and has been widely applied. However, at a global scale the relative importance of each component varies widely, from recent carbonates (such as in the Caribbean) presenting high primary porosity to, at an opposite end, very low matrix porosity in old (e.g. Proterozoic), recrystallized carbonates, common in the ancient cratonic basins in South America and Africa. In the latter, primary porosity has normally been obliterated due to recrystallization, burial and exhumation episodes, and various high temperature and pressure episodes. Interconnected pores tend to be rare and these carbonates display limited storage capacity, behaving mostly as a dual porosity system, with flow and storage mostly concentrated in fractures and conduits. Furthermore, the same post-depositional events that decrease matrix porosity may also lead to the sealing of joints, further limiting the validity of the triple porosity assumption. This study addresses the main differences related to flow behavior in karst aquifers that do not display significant primary porosity and how these affect the interpretation of flow regimes. It further aims to highlight how they differ when compared to "classical" triple porosity karst aquifers. Recognizing the range and the relative importance of each porosity type is important for fully understanding the heterogeneous nature of karst aquifers. The low porosity extreme may be common in deep carbonate sequences hosting oil reservoirs, being critical in keeping the sealing capacity of such units. Moreover, it could also prove to be crucial when considering the potential of using depleted carbonate reservoirs as carbon storage facilities.

Keywords: karst aquifers, triple porosity, ancient carbonates

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The RETURN project's approach to sinkholes, the most typical geological hazard in karst terrains

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Abstract

The RETURN (multi-Risk sciEnce for resilienT commUnities undeR a changiNg climate) project is managed by a Foundation funded by the European Union Next-GenerationEU. Within the framework of the project, started on December 2022, and that will last three years, the Spoke2 "Ground Instabilities" deals with processes of instabilities including landslides, sinkholes, subsidence and liquefaction. In this abstract we present some preliminary outcomes of the activities so far carried out as concerns sinkholes, the most typical geological hazard in karst. Even though RETURN also takes into account sinkholes of anthropogenic origin, developing in many Italian towns in consequence of the extensive presence of artificial cavities, in this contribution we focus on natural sinkholes, due to the theme of the Eurokarst congress.

In Italy, natural sinkholes of different origin are widespread in all those areas characterized by outcrops of soluble rocks, both as carbonates and evaporites. Following the project's framework, sinkholes are being analyzed in terms of the predisposing factors as well as of preparatory and triggering processes. The distinction among them is made on a temporal basis: predisposing factors are considered invariable at the observation scale, while the preparatory factors show trends or periodic variations in the same time interval. As a consequence, a trigger is considered as a process which acts over a very short and well-defined time. Further, sinkholes are distinguished also on the basis of their kinematics: according to the internationally accepted sinkhole classification by Gutierrez et al. (2014), collapse sinkholes are included in the category of rapid processes, whilst solution, sagging and suffosion sinkholes belong to the slow-processes category. The activities carried out in the first year of RETURN project brought us to collect a number of learning cases dealing with sinkholes in Italy, and to deduce rationales of process to be considered as tools for operative chains in view of the implementation of a scenario producer to be designed through an IT-technology. The outputs expected in the simulated scenarios are quantitative values attributed to ground

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instability effects (among which the sinkholes) in a multi-hazard perspective, with the final goal to derive mitigation strategies for multi-hazard.

Reference:

Keywords: sinkholes, hazard, vulnerability

TOPIC 3
Karst geomorphology and landscape
POSTERS

Complementary use of hydrodynamic and hydrochemical tools to infer groundwater-surface water interactions in rivers located in alpine karst environments. The Segura and Zumeta rivers (Jaén province, SE Spain)

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Abstract

Knowledge of surface water / groundwater interactions in high mountain karst regions is crucial for enhancing the protection and management of water resources. This is particularly relevant when dealing with mountainous areas located in the Mediterranean region, such as Sierra de Segura (SE Spain), one of the largest carbonate outcrops (3000 km2) in the Iberian Peninsula. This region acts as headwater of rivers flowing eastward (Mediterranean Sea) and westward (Atlantic Ocean) over Cretaceous-Tertiary limestones and dolostones. However, information on the surface water-groundwater interactions in rivers and streams found in the area is still limited, as well as their role in the functioning of the carbonate aquifers. This research shows the preliminary results obtained from hydrological (flow-rate) and hydrochemical records (electrical conductivity -EC-, temperature, major ions, total organic carbon -TOC-, dissolved gases -O2 and 222Rn-) measured along two of the main rivers in the area (Segura and Zumeta). 218 discharge and physico-chemical parameter measurements were carried out during the hydrological year 2022/23 in 23 points spread along 20 km of each river.

In general, a progressive increase of flow-rate is observed in Segura and Zumeta rivers, from 240 to 1915 l/s and 11 to 784 l/s, respectively. Water chemistry evolves from calcium-bicarbonate *facies* to calcium-magnesium bicarbonate along the Segura and Zumeta valleys. In this sense, the carbonate substratum and the different incision degrees in the fluvial network (deeper in the Segura River) result in a distinct chemical behaviour for each river, particularly near the gaining river stretches (up to 3 in Segura and 2 in Zumeta). Moreover, stream-path evolutions of flow and physico-chemical parameters show a certain relationship in both rivers, with three stretches in Segura and one in Zumeta where values of temperature, EC, and dissolved oxygen (O2) strongly decrease due to groundwater inputs to the riverbeds. Increases in 222Rn activity (up to 700 Bq/m3) also occur simultaneously in the same areas. However, rises in water mineralisation, Cl-, (from 2.6 to 6.1 mg/l), and radon activity were found in one stretch in Zumeta River with low O2 concentration (6.2 mg/l), indicative of groundwater discharges with higher residence times into the aquifer and from slightly drier recharge areas (soil evapo-concentration). In this last stretch, groundwater is

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[*]Speaker

diffusely discharged to riverbed throughout alluvial sediments, causing more inertial variations in flow-rate than in other locations with higher O2 concentrations.

Hydrodynamic tools combined with the spatial distribution of physical-chemical parameters, including dissolved gases have allowed us to understand the different dynamics of surface water / groundwater interactions in the studied rivers. Thus, hydrological evolution of Zumeta River is related to the inertial behaviour and the higher residence times of groundwater. In the Segura valley, the higher incision rate, the carbonate rocks, and the karstic gaining river stretches result in active fluvial dynamics with strong hydrochemical changes. In this sense, geomorphological / hydrodynamic setting, groundwater–rock interaction, recharge, or a different combination of these processes are responsible for the location of gaining river stretches but also for the different hydrochemical evolution in both rivers.

Keywords: Karst, geomorphology, surface, groundwater, interaction, aquifer

Estimating gypsum dissolution rates and comparing with limestone formations of Iran: case studies of Gachsaran gypsum formation in Maroon basin of Zagros and Kalat limestone formation in Kopet-Dag

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Abstract

Evaporite formations are the main beds for the formation of karst forms. The Maroon plain is located in the simply folded Zagros belt in the provinces of Khuzestan and Kohgiluyeh-and-Boyer-Ahmad. The Kalat mountain basin in the Kopet-Dag zone is also the bed for the formation of limestone sinkholes due to the presence of carbonate limestone formations. This study aimed to determine the dissolution rate of gypsum by estimating the dissolution rates of cations and anions dissolved in the samples taken from rainwater and runoff flowing on the Gachsaran formation. An attempt also made to reveal the differences and similarities in this area in terms of dissolution rate of limestone formations. For this purpose, the rainwater samples and several samples from different parts of runoff collected at different times in a 6.2 hectares sub-basin in the Maroon plain after eight hours of runoff monitoring. The amount of salts from the dissolution of gypsum and other ions in runoff revealed an average of 6.6 tons of gypsum rock per year removed as solution. Moreover, it takes 71 years to form a sinkhole with a volume of 376.4 m3. The dissolution rate of gypsum per 100 years is 23 cm, while in another study; The limestone area studied by Rezaei Arefi et al. (2019) is the Kalat mountain with an area of 168.37 square kilometers is located 145 km north of Mashhad in Khorasan Razavi province, used the data such as the measurement of surface runoff of the basin, the results of continuous measurement of electrical conductivity and temperature of surface water. In this study, several methods such as Corbel equation, Sweeting equation, Xiong model and laboratory methods including measurement of limestone in sediment by calcimetric method, ICP method, water hardness and density of basin rock method, measurement of CO2 content in rock, and weighing test method were used. the dissolution rate of limestone estimated to be 0.236 cm per 100 years. Thus, the dissolution rate of gypsum calculated to be almost 100 times the dissolution rate of limestone.

Keywords: Sinkhole, Iran, Gachsaran formation, gypsum karst, calcareous karst, Maroon plain, Kalat mountain, Kopet, Dag formation.

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Karren on Miocene Carbonate Sandstones in Tourrettes-sur-Loup (Provence, France)

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Abstract

We have conducted thorough karstological research in the Provence area (France), more specifically, in the village of Tourrettes-sur-Loup in order to shed light on the karren karst rock relief, which tells us a great deal about its formation and development. In the field, we described the morphology of the rock in detail and took several rock samples for microscopic examinations.

Karren have developed on Miocene carbonate sandstones deposited on limestone folds. The shape of karren is mostly dictated by the rock, in addition to their development process. It is the first description of the development of karren formed on this type of rock. A thorough examination of the karren rock relief and of the rock on which they were created explains how they have formed and developed. The special features of karren formation on this unique rock within an otherwise typical development model are broadening our understanding of the formation of the rocky karst surface.

The characteristics of the "plastically" deposited sloping, uniquely composed and predominantly uncracked beds of Miocene carbonate sandstones, which have a major impact on the formation of karren, are intertwined with the typical rock relief development model, which reveals a transition from subsoil formation to denuded rock exposed to rain. Rock denudation is gradual and the water often flows onto the bare rock from the soil covers. The bare, sloping peaks reveal the characteristic formation of a slightly inclined and relatively smooth rock. Such surfaces are initially shaped by sheet flow; steps are a characteristic trace of that. As the surface is being dissected, the water begins to merge into streams and channels are formed. Along these channels, the rock is becoming increasingly dissected. That indicates the initial stage of the formation. The composition of the rock that is splitting, especially under the moss, does not enable the development of the smallest rock forms, such as rain flutes, whereas its splitting causes the development of rounded peaks.

Keywords: karren, lithology, rock relief, France

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Leveraging high-resolution in-cave LiDAR products for the detailed geomorphological mapping of cave passages

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Abstract

In karst landscapes, the dissolution of limestone occurs across many scales and the majority of flow is conducted through the conduit network. Within the frame of current flow and transport models estimating head losses and flow along a conduit requires estimating two main parameters: hydraulic diameter and roughness. The first can be roughly estimated from the topometric data of traditional cave surveys, while the second is usually sampled from a range of plausible values. Therefore, applications that deal with the actual mechanism of flow and transport need a realistic representation of the conduits across micro- to meso-scale, and an understanding of the local speleogenesis.

However, a fundamental challenge in modelling flow and transport in karst is the representation of the complex three-dimensional geometry of conduit systems, which is further complicated by the diachronous nature of the functioning of cave levels. This representation can be achieved by collecting field data by mapping the cave passages of interest in detail which, in turn, help tune stochastic simulations of passage geometries. Strategies to address the former requires surveying the cave passages and analysing their geometry and spatial organisation, carrying out detailed geomorphological mapping, and evaluating the lithological as well as structural setting in which the cave developed.

In this, the increasing use of LiDAR technologies allows the precise mapping of real cave passages wherever they are known and accessible, and bridges many scales of observation.

Using a combination of traditional cave survey techniques and a handheld mobile LiDAR scanner, we acquire and georeference dense point clouds from several caves across the Swiss Jura and the French Alps. We compute high-resolution meshes of key passages to perform the calculation of geometric indicators from mesh. We leverage the high resolution data together with field observations to build a detailed speleogenetic interpretation of the cave passages. We also present the results from structural and geomorphological analyses spanning the micro-scale (by identifying and classifying e.g. scallops, phreatic pockets, potholes) to the meso-scale such as along-conduit geometric attributes like section area, solidity or circularity. We highlight the value of generating new morphometric indicators adapted to the complexity of cave datasets to calculate equivalent hydraulic radii, or along passage roughness, both of which can be used to inform cave-network scale models of flow and transport.

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Middle-Upper Pleistocene paleoclimate evolution from travertine records of the Guardal River headwaters (NE Granada province).

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Abstract

The petrological and geochemical characterization of the travertine deposits associated with the headwaters of the Guardal river, located in the NE of the province of Granada, has been carried out. From this characterization, the paleoenvironmental and paleoclimatic implications of the presence of these carbonates in this context are discussed.
The samples have been studied by optical and electron microscopy and analyzed chemically and mineralogically by X-ray fluorescence and X-ray diffraction. Carbon and oxygen isotopic analysis and chronological dating by U/Th have also been carried out.

The mineralogy is mainly carbonate. The other mineral phases present correspond to silicates and exceptionally minority amounts of iron oxides and oxyhydroxides, which in general come from the erosion of the existing materials in the area. Geochemical analyses indicate that the calcite may contain some magnesium.

The $\delta 18O$ values of between -7 and -9 ‰ (V-PDB), are compatible with an origin of the travertines from meteoric waters. Values of $\delta 13C$ of -7 to -10 ‰ (V-PDB) are indicative of a CO_2 provenance from atmospheric origin and edaphic contribution. In general, these are similar values to those described in other travertines from similar geological and climatic contexts.

Dating by the U/Th method allows us to differentiate four generations of travertines, the oldest between 120,000 and 140,000 years that can be assigned to MIS 5e, another generation between 80,000 years (MIS 5a), another stage between 30,000 years (MIS 3) and the last younger one that would correspond between 20,000 years and 18,000 years (MIS 2).

Calculations of paleotemperatures from isotopic $\delta 18O$ values of travertine and $\delta 18O$ of present-day waters yield values similar to those described for present-day waters in the headwaters of the Guardal river.
The facies, crystalline morphologies, mineralogical and geochemical compositions, as well as carbon, oxygen isotopic signals suggest that these deposits were formed from waters with temperatures between 10-15⁰C, supersaturated in $CaCO_3$ and with Mg, Fe, Na, Cl and Si contents.

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POSSIBLE EXISTENCE OF HYPOGENE KARST IN CROATIA

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Abstract

In the past twenty years, a lot of research has been focused on karst areas whose genesis is linked to so-called hypogene karst. Croatia is no exception. Thus far, there are no published papers on the occurrence of hypogene karst in Croatia. However, there are evidence of simultaneous acts of fresh water and salt water during speleogenesis, which could be linked to possible existence of hypogene karst in Croatia. Factors that are required for the formation of hypogene karst can be different and over time the knowledge about them is expanding. Some authors define hypogene caves as cavities created by aggressive action of water underground, but without the influence of CO_2 from the soil or some other source of acidity from the terrain surface. The mentioned geochemical definition later expanded into so-called hypogeological definition. Majority of published papers suggest that hypogene karst is a significant component of fluid-induced lithogenesis and plays an important role in the development of porosity and permeability in many sedimentary and some metamorphic rocks. Comparing certain areas around the world with karst in Croatia, it can be concluded that there is a possibility of hypogene karst appearing in Croatia.

Comparing the occurrences of hypogene karst in Austria with the area of Hrvatsko Zagorje and Banovina, it is possible to see similarities. Deep faults with mineral and thermal waters and a higher percentage of CO_2 could have played a major role in creation of hypogene karst. This could be linked with the occurrence of suffusion in Banovina region, Ravna Gora and Strahinjčica.

A large number of hypogene caves in the world ware found next to springs in which the water rises from the depth along deep faults. Such examples can be found in several springs deeper than 200 meters in Croatia. Due to morphology of the cave channels, there is a possibility of hypogene karst existence in the interior of Una river spring in Lika, where divers reached the depth of 248 meters.

A certain number of hypogenic caves in Europe developed along the contact between Paleozoic and Mesozoic rocks due to aggressive water. Such speleological objects might exist in Croatia on the northwestern slopes of Mount Velebit and in Gorski Kotar (Ličanka river spring, Fužine).

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The literature mentions a considerable occurrences of hypogene karst at the mixing points of fresh, sulfur and salt (sea) water. The coastal part of Croatian karst abounds with underwater fresh water springs or vruljas. Some well-known vruljas under Biokovo and Omiška Dinara massifs are over 160 meters deep. Furthermore, there is a large number of deep and long vruljas under the Velebit massif. There are indicators that some of them were formed by hypogene speleogenesis such as sulphur caves near Dubrovnik.

We can conclude that recent research in some well-known caves in selected areas of Croatia can expand knowledge about the occurrence of hypogene karst.

Keywords: Hypogene, karst, speleology, Croatia, Speleogenesis

TOPIC 4
Cave monitoring and management
ORAL PRESENTATIONS

Environmental monitoring of Cueva Larga (Sierra de los Filabres, Almería) as support for the interpretation of paleoclimatic records from speleothems

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Abstract

Secondary carbonates from caves (e.g., stalagmites) are valuable for reconstructing past climate conditions. Environmental monitoring of the underground atmosphere is necessary to understand the present microclimatic dynamics and facilities the interpretation of geochemical records obtained from stalagmites. This study is focused on the environmental monitoring of Cueva Larga cave that is located at 1850 m a.s.l in the Sierra de los Filabres mountain range (Almería, southeast Spain). The current climate in the cave setting is semiarid (approximately 170 mm/year recorded over the last 10 years) and mean daily air temperature ranges from -8 ⁰C to 23 ⁰C in the cold season (June - September) and from 14 ⁰C to 32 ⁰C in the warm season (November - May). Both the external environment of the cavity (precipitation, temperature, relative humidity, barometric pressure and wind) and its internal atmosphere (temperature, relative humidity, drip rate, atmospheric pressure, carbon dioxide and radon contents) have been monitored for more than a year. Additionally, drip waters and current calcite precipitates deposited on artificial glasses are periodically sampled for isotopic analysis ($\delta13C$ and $\delta18O$). The cave air temperature is relatively constant (11.7 ⁰C on average), while relative humidity ranges from 25 to 100%. The cavity is well-ventilated, as the recorded values of carbon dioxide and radon are relatively low (482 ppm and 189 Bq m-3, respectively). We also found that drip rates are mainly influenced by rainfall amount and variations in external barometric pressure. The drip rates exhibit a negative correlation with barometric pressure, except during periods when cumulative rainfall exceeds 30 mm/h. Under these circumstances, the drip flow increases over fourfold compared to its baseline. The results of this study will contribute to a better understanding of the cavity's response to external environmental changes and how the climatic signal is transferred to the chemical composition of its stalagmites.

Keywords: microclimatic dynamics, cave ventilation, drip rates, stalagmites

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Groundwater water level and block movement monitoring in the Han-sur-Lesse cave (Belgium) : tools to improve visitor access and security

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Abstract

Located in the Famenne-Ardenne UNESCO Global Geopark, the Han-sur-Lesse cave is a major attraction of Wallonia with a frequentation of about 300 000 tourists per year. The cave is a double shallow-hole – resurgence system developed in the Givetian limestones with a development of 10.7 km galleries. The river Lesse sinks in the " Gouffre de Belvaux " that is the main swallow hole of this karst with a maximum capacity of 25 m^3/s. At this flowrate, the cave is flooded and some sections become inaccessible for the touristic activities. During floods, upstream some narrow sections or sumps, water level can rise up to 10 meters creating unusual hydraulic pressure that could destabilised screes on which touristic footpaths are constructed. To quantify these processes, water level probes were installed and topographic nails were fixed on different cave roofs or walls and blocks.
Thirteen water level probes were installed inside the cave : nine along the underground Lesse River, one the river at the main swallow hole and one at the resurgence, and two are connected with the Givetian aquifer. All of them were levelled with a precision of one centimetre. Results allow to have a better understanding of the underground flow dynamics and of the relationship between the underground Lesse River and the aquifer. Established correlation between river discharge and the groundwater level inside the cave will allow a better management of the touristic activities.

An instrumentation was also implemented to quantitatively assess possible block movements in the cave. Measurements are monthly conducted with portable devices at fixed stations located in the cave at specific locations : strata, rock blocks, paths, ... The first method consists of measuring variations in slope, using a precision clinometer. The device can measure slopes between 0 and 90◦ with an accuracy of around 5 arcsec (angular deviation of 0.02 mm/m). The second method consists of measuring variations in length between two points using a Disto-Leica with the aim to be able to quickly carry out movement checks (1 mm) in many places in the cave. Rigid supports, specially designed for this device, are sealed at locations to be checked and allow to aim the same point. If the support is "stable", then the targeted point is considered as unstable, otherwise, it is the opposite.
During this long-term monitoring, every change of parameters (water levels, tilts, distances, ...) must be interpreted in terms of potential modifications of the karst system requiring detailed investigations.

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[*]Speaker

Insights on groundwater-surface water interactions in the Frasassi karst system (Central Italy)

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Abstract

The Frasassi karst system, also named the Fiume-Vento karstic complex, represents the most important Sulfuric Acid Speleogenetic (SAS) system in Central Italy, characterised by hypogenic caves affected by an active flow of sulfidic water draining toward the Sentino Stream gorge. Groundwater circulation (GW) occurs in submerged karst conduits, and the water table can be reached in some lakes in the inner part of the karst system. Hydrogeochemical campaigns during the 2001, 2007 and 2020-2021 periods allowed the identification of two distinct water types: Ca-Mg-HCO3 water and Na-Cl-SO4 water. Freshwater (Ca-Mg-HCO3 water) characterises the shallow part of the underground lakes and is fed by percolating water and/or water draining from the stream towards the karst system (stream-aquifer interaction). Stratification and dilution phenomena between freshwater and sulfidic water occur in many lakes. The accumulation of freshwater in some inner lakes is responsible for siphoning phenomena that produce the rise of saltier waters towards neighbouring lakes. Remain open if freshwater input producing the siphoning is driven mainly by percolating water or stream-aquifer interactions. The geochemical analyses strengthen the hypothesis that stream-aquifer interactions do not propagate to the inner parts of the karst system but are detected in its outermost parts. The system's outflow (sulfidic springs) interacts with the Sentino stream water (SW) in the northern-eastern part of the karst system, which experienced important flooding, the latest of which occurred in November 2013 and September 2022. The last flooding caused damages and disruption in many municipalities of the central-north Apennines ridge. It produced vertical and lateral changes in the streambed with massive accumulation of alluvial deposits. During the flood, a huge increase in the stream water level (more than 4 m) was monitored, producing SW ingress to inland lakes as documented by residues of vegetation found within some of the karst caves. More than a year after the flood, some sulfidic springs along the Sentino Gorge are no longer visible since alluvial sediments occluded the karst conduits that drained the water towards the stream. A recent survey highlighted a new sulfidic spring emerging downstream of those mapped in the past, indicating that a change in the groundwater path feeding the springs occurred. No studies have updated the GW-SW interactions in the karst complex after the flood. In this framework, the research presents a new hydrogeochemical campaign on some inland lakes' waters to understand better GW-SW interaction. The main objective of the work is to document the effect of extreme meteorological conditions on the hydrodynamic response

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of a structurally complex karst aquifer. The study's results can improve understanding GW circulation and dilution phenomena in other karst systems characterised by SAS-type speleogenesis.

Karst system conceptual models based on the aquifer recharge

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Abstract

The aquifer recharge heavily affects both the hydrodynamic and the main water chemical-physical parameters. The recharge of the aquifer is mainly linked to primary and/or secondary inputs: the primary inputs are by rain or snow melt, directly recharging the aquifer, whereas the secondary inputs are the surface runoff waters continuously recharging the aquifer. Taking into account the recharge of the system, four different basic conceptual models can be distinguished: *systems with primary inputs prevailing, systems with primary and secondary inputs, systems with secondary inputs prevailing, systems with prevailing inputs by racking* (Vigna 2023). Monitoring with multiparameter probes (continuous acquisition of water levels/flow rates, temperature and electrical conductivity of spring waters) allows to highlight the different recharge models.

Systems with primary inputs prevailing (e.g. Fuse system, Ligurian Alps, Piedmont, Italy) are characterized by a diffuse water infiltration, homogeneously distributed into the entire hydrostructure. The aquifer recharge occurs only during precipitation or snow melt periods. Therefore, water spring flow rate, mineralisation and temperature are linked only to the groundwater circulation (karstification and/or prevailing fracturing).

Systems with primary and secondary inputs (e.g. Borello system and Bossea system, Ligurian Alps, Piedmont, Italy) are recharged by precipitations directly affecting the aquifer, and by surface watercourses continuous inputs, which flow on the poorly permeable rocks confining carbonate rocks through in sub-riverbed sinkholes. In this systems, water temperature and mineralization may undergo temporary and marked variations after the two inputs mixing.

Systems with secondary inputs prevailing (e.g. Mondini system and Bandito system, Ligurian Alps, Piedmont, Italy) are usually located near valleys in which important watercourses flow on carbonate rocks. When these watercourses intercept the carbonate aquifer, progressive water losses in sub-riverbed occur. In dry seasons, these losses can be total or partial. The so-called "hydrogeological tunnels" belong to this kind of systems too. The water flow rate and chemism are heavily conditioned by the hydrodynamic and qualitative characteristics of the surface waters, being the primary inputs negligible. The spring water temperature generally shows important fluctuations, closely related to the seasonal climate variations.

Systems with prevailing inputs by racking (e.g. Rio Martino system, Cottian Alps, Piedmont, Italy) are usually karst aquifers covered by extensive porous aquifers (debris, morainic or alluvial deposits), which are mainly fed by the aquifer in the surface area. The spring

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water flow rate, mineralisation and temperature are affected by the hydrodynamics of the porous aquifer, which generally have more constant values over time (due to a relatively low permeability due to the presence of a fine matrix) and, consequently, more contained fluctuations of different parameters than those typical of the karst aquifers.

In this work, several case studies of springs fed by the different aquifer systems are reported.

Keywords: karst systems, aquifers, water, karst, monitoring

Prehistoric caves facing the climate change: New sensors for an effective conservation strategy

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Abstract

Over the past few years, the environmental monitoring of shallow decorated caves (less than 40 m deep) has revealed a general increase of underground temperatures that can locally reach 1.3∘C per decade. The disparity in heating between deeper parts and shallower parts of caves may trigger significant changes in the internal aerology. Prehistoric paintings and engravings are generally situated at a rock/thin water-film/atmosphere interface that should remain as constant as possible to limit the deterioration of rock art heritage. Indeed, according to the moisture content of cave air and the relative temperatures of cave wall and humid air, any change in cave aerology may either grow by condensation or dry up the thin liquid film that covers the cave paintings. When the thin water film evaporates, a carbonate precipitate is deposited on the wall that impairs the readability of paintings. When the water film thickens, the painting pigments may be re-suspended in water and the cave painting may be washed out in the extreme case. The previous conservation strategy that has relied on a stable underground microclimate cannot be sustained any longer. To address the current climatic changes that are observed in prehistoric caves, new observational techniques are being developed by our team: (a) to assess the slow air motions in cave galleries, a flag sensor made from a mylar sheet stiffened by balsa sticks which deflection is followed by a position sensor (1s measuring step interval), was set-up to detect air velocities as low as 1 cm/s after calibration. (b) The thickness of the thin water-film in the 25-200 μm range can be measured on-site using a confocal optical sensor (Micro-Epsilon) at a 100 Hz measuring rate; from our experience on 6 prehistoric caves, the dynamics of the water-film is controlled by surface tension effects on cave walls, and by the dripping rate on speleothems. (c) Piche evaporimeters are used in caves to monitor the evaporation rate in cave air; an automated version was developed from a capacitive measurement carried out by a printed circuit in the graduated glass tube; data are stored on a SD card which enables the increase of survey frequency while decreasing the number of field missions. (d) Laser optical particle counters were used with a 15 min time interval to detect air directly incoming from outside, aerosols from speleothem dripping, and local contamination due to the motion of people around. (e)

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*Speaker

Finally, to reduce the carbon footprint of field missions, an IoT solution was developed to remotely control the correct functioning of measuring devices and to transfer part of the data to the lab. A local LoRa/ESP32 network is used to export the data from the devices inside the cave to a gateway placed at the cave entrance. This gateway then sends the data to the lab via the Iridium satellite constellation. All the caves (Esparros, Pech Merle, Gargas) in the study have been monitored for various climatic parameters (air/wall temperature, CO_2 concentration, relative humidity...) with a 15-minute time-step since the mid-nineties/early 2000s.

Keywords: Cave monitoring, climate change, slow air motion, thin water, film, particle counting, IoT solution

Radon exposure and health risks for cave guides and speleologists

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Abstract

Radon is a radioactive trace gas that is originated from uranium decay and released into the atmosphere from rocks and soils. It tends to accumulate in confined environments, representing the largest source of exposure to ionizing radiation for humans. Inhalation of radon and its progeny can cause DNA damage in the lungs, as the emitted alpha particles interact with biological tissues, increasing the risk of cancer with prolonged indoor exposure. Like in many other countries, radon concentration is also regulated in Italian indoor workplaces, underground and ground floor spaces, with a maximum national reference level of 300 Bq/mc (200 Bq/mc for dwellings built after 2024) (Law 101/2020). Although carbonate rocks do not release radon, caves are considered as indoor environments with significant concentrations of radon-222, especially in locations with poor ventilation. Because karst rocks are permeable geological features, this geogenic gas can migrate to the surface via fractures and cavities. According to a recent study, approximately 25,000 people are employed directly as managers and guides in the global business of show caves, which attracts more than 70 million people every year. However, this number does not include researchers studying subterranean ecosystems, who spend an unquantified amount of time underground. Tourist caves, as occupational exposure sites, require appropriate radiological protective measures for cave workers, as well as monitoring programs for the evaluation of the subsurface fluctuation of radon-222 levels. This approach was adopted at the Su Mannau Cave (Sardinia), a large karst system (more than 8 km long) formed in Cambrian carbonate rocks, with a 300 m long tourism stretch that attracts over 15,000 tourists each year (the cave is closed to the public from November to March for micrometeorological recovery). Radon-222 measurements were carried out using passive nuclear track detectors (CR-39) to determine the radon concentration in the short area of the cave accessible to the public. Six dosimeters were placed along the cave paths, in selected areas where guides spend most of their time during explanations. Radon monitoring was carried out during an observation period between February 2019 and May 2020, with four exposure intervals selected according to the expected seasonal patterns. The results show that radon concentration in Su Mannau Cave ranges from 300 Bq/mc to 3,500 Bq/mc, with an average of about 1,350 Bq/mc. Higher radon-222 levels were recorded in the deepest part of the cave. Additionally, seasonal changes in Rn activity have been

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observed with higher concentrations in the summer and lower concentrations in the winter. Although a previous regional survey classified the karst area where Su Mannau Cave is located as having a low probability of exceeding the national reference level (RAS, 2022), this research highlights a discrepancy between generalized studies and the actual Rn exposure risk for cave workers, emphasizing the importance to implement radon monitoring programs in show caves.

Keywords: cave monitoring, cave management, ionizing radiation, Su Mannau Cave

SEDIMENT FEATURES AND FORAMINIFERAL ASSEMBLAGES IN THE FICARELLA CAVE (SAN VITO LO CAPO, SICILY, ITALY)

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Abstract

The submerged and partially submerged marine caves are protected in the framework of the EU Habitats Directive because they are peculiar environments from a geological and geomorphological point of view, but also as biodiversity hotspots. However, while the hard-bottom communities are relatively well-studied, only recently their sediments' chemical and physical characteristics, associated with their microfaunal content (benthic foraminifera), have been focused on. A project started in 2013 aimed at characterizing the Mediterranean marine caves concerning these aspects, with results applicable in protecting and conserving these environments and studying large-scale environmental changes. In this context, the sediments of the Ficarella cave were analyzed to identify different ecozones inside the cave and verify the supply of organic matter and microplastics.

The cave, which is located on the eastern side of the San Vito Lo Capo peninsula (Northwestern Sicily), is constituted by the dolostones, limestones, and dolomitic limestones of the Panormide domain (Upper Triassic - Lower Cretaceous), densely affected by normal faults, mainly with NW-SE direction. Coastal gravity and karst landforms, such as dolines, canyons, and caves, testify to the interaction between Quaternary tectonics and climate changes.

Divers surveyed the cave to reference the sampling station in the environment and define the cave morphology. The cave is characterized by a wide entrance about 23 m below sea level, and sandy sediments are on the bottom of the cave. In the internal parts, the cave changes morphology, there are numerous fallen blocks, and the water depth decreases up to an emerged part in the innermost sector, where there is evidence of freshwater input.

Along the existing mainline were positioned, starting from the entrance, 10 sampling stations at 10 m distance each, but only on 5 stations was possible sampling because of the presence of rocky outcrops in the others. Divers manually collected distinct aliquots of surface (0-2

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cm) sediment for the analysis of grain size, organic geochemistry, microplastics, and benthic foraminifera (rose Bengal stained), while water parameters (temperature, salinity, and dissolved oxygen) were recorded using a multiparametric probe.

Analyses of abiotic parameters and microplastic contents in sediments and organisms are still in progress, while preliminary results of the quantitative analyses of foraminiferal assemblages are available. Benthic foraminifera were found in the whole cave, with exceptional diversity (107 and 39 species in the dead and living assemblage, respectively), and a clear gradient with the distance from the entrance was recognized in the species distribution. The increase of typical species of Mediterranean marine caves was evident, while typically, marine species of hard and vegetated bottoms sharply decreased in the innermost cave. The presence of symbiont-bearing taxa up to the middle of the cave pointed to the presence of enough light for photosynthesis.
This study represents a further step in studying the cave ecozones and their application to studies related to the environmental changes occurring rapidly in the Mediterranean basin.

Keywords: marine caves, benthic foraminifera, ecological indicators, marine sediments

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Setting up a monitoring network to characterize the hydrological functioning regimes of the Saint-André-de-Cruzières karst system (south France)

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Abstract

The Saint-André-de-Cruzières karst is developed in a 40 km^2 syncline structure of Jurassic limestones over Triassic marls. It is located in Ardèche (south France), in a mediterranean climate area characterized by a long summer drought (May to September) and heavy rains in autumn. Two types of waters recharge the karst system: losing stream draining sandstone watersheds and direct precipitations. The system presents a permanent spring and several intermittent Vauclusian springs. The spring's hydrological response times to precipitation are short (hour to tens of hours). The karst water is mostly unexploited, with only two small drinking water boreholes. With climate change and increasing touristic pressure on water resources, this karst aquifer would become an interesting reservoir of water during the summer. Nevertheless, its use is limited by the poor knowledge on its hydrogeological functioning and its exposure to domestic and agricultural contaminations.

The karst system includes over 38 km of explored caves in different branches. Upstream on the west, the karst branches present a fossil network which is equipped for tourism (La Cocalière, 120,000 visitors per year) above an active network with permanent streams. During low flow, these streams disappear in narrow and unknown conduits and their water reaches the permanent spring at the east of the system. During floods, hydrological connections are different and karst water flows out through several intermittent Vauclusian springs, at the north, the south and the east of the system. On the east, the karstic network is permanently saturated and can be explored only up to -80m. The hydrological connections between the branches during high flows and the origin of the water of the different springs are unknown. This lack of knowledge limits water management strategies, becoming critical with increasing pressures.

To improve this knowledge, we deployed a network of sensors in 2023 to measure pressure, temperature, and electric conductivity: 23 Sensus-ULTRA (Reefnet) and 4 CTD-Diver (SDEC) sensors. Measurements were done with a 5-minute time step in stations located in the different branches of the karstic system. In addition, times series exists at the permanent

*Speaker

spring and a rain gauges network covers the area. During the 2023 autumn, three rainfall events presenting intensities exceeding 50mm in 6h activated the upper branch on the system. For each event we determined which branches of the karst were active and the relative timing of the flood in each location. This work allowed us to propose a conceptual model of the hydrological functioning of the karstic system. We will present the monitoring strategy and the functioning regimes observed for different water levels and precipitation intensities.

Slope-scale deformation driven by enhanced karstification: new insights from the case study of the Peschiera Spring slope

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Abstract

Identification and understanding of pre-failure events are crucial for mitigating risks associated with massive rock-mass failures. Large-scale processes, such as rock mass spreading or sliding, can be influenced by changes in local stress conditions caused by periodic hydraulic or seismic events. These changes can lead to rapid acceleration or impulse on slow viscous deformations, potentially resulting in rock failure or collapses. Recognizing a transitional from slow-to-fast strain rate is crucial as it may indicate more intense deformational evolution or a widespread failure.

To address such a geohazard, an integrated approach which combines geotechnical and geophysical monitoring is fruitful as it helps to study the temporal progression of slope movements and assess signals that may precede instability or indicate ongoing acceleration. In complex geological settings, such as karstic pervasively fractured rock masses with hydraulic circulation, understanding future variations in hydraulic stressors is essential.

This study focuses on the Peschiera Springs slope, which hosts the drainage plant of the Rome aqueduct, as it exemplifies collaborative efforts between researchers and local companies to mitigate geological risks and manage infrastructure effectively. The Peschiera slope, located in Central Italy almost 80 km from Rome, is characterized by a monoclinal N-dipping structure dissected by major fault lines and minor joint sets. Hypogeous karst processes contribute to generating sinkholes and collapse dolines.

The slope experiences a gravitational deformation process involving rock lateral spreading, leading to various landforms like sinkholes and scarps. The study reports on almost a decade of monitoring using a dedicated system that evolved in technology and resolution. This monitoring system continuously collects data to characterize the deformation process.

Over the last decades, the deformations related to mass rock creep and favoured by the karstic process, requested restoration design of the plant consisting of prompted consolidation interventions and extraordinary maintenance of the main Drainage Collector Tunnel (DCT). Moreover, a redundant geotechnical monitoring system was installed during tunnel restoration, featuring sensors like MEMS arrays, borehole extensometers, wire extensometers, load cells, and triaxial crack meters.

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The study's recent outcomes showcase the kinematics of the deformation process, assess the mechanical response of the consolidated DCT, and identify areas of interest with localized deformations. Ongoing geophysical monitoring aims to detect signals of microseismic events generated by underground instabilities.

Results from multitemporal LIDAR acquisitions reveal morphological changes on the slope's surface, aiding in sinkhole inventory and identifying deforming sectors. Continuous monitoring with radial MEMS arrays confirms a stationary trend of creep deformation. The distribution of horizontal and vertical displacements suggests a downward back-tilting of the slope block, influencing the internal part of the DCT.

Nanoseismic monitoring records far-field teleseismic earthquakes and local microseismic events, characterizing different event typologies. Some microseismic crises show precursors tens of minutes before significant collapses. These data, integrated with accelerometric measurements, support risk mitigation strategies, aiding in the computation of control indices for alert levels and warning systems adopted by the aqueduct owner. Overall, the study emphasizes the importance of comprehensive monitoring for understanding and mitigating geological risks which threaten such a relevant infrastructure.

The role of cave monitoring in the pathway towards the sustainable energy transition

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Abstract

The *"Low carbon and Clean Industries"* research priority of the European Green Deal refers to the carbon cycle and, more generally, to a more efficient carbon management to achieve zero net emissions by 2050. Among the numerous solutions tested to move away from traditional waste economy to the circular carbon economy (CCE) includes carbon dioxide (CO_2) capture and storage (CCS). In terms of perspectives, carbon storage in deep geological reservoirs constitutes a technique with high potential for mitigating the effect of greenhouse gases (GHGs) in the environment. There are two broad categories of risks potentially associated with the leakage of CO_2 from geological storage sites: (1) those deriving from the effectiveness of the reservoir boundary conditions necessary for the CO_2 containment and (2) those related to health and safety of the environment. The latter are caused by: (a) the increase in CO_2 concentrations in the surface environment due to the gas migration from the subsurface into the atmosphere, (b) the chemical effects of dissolved CO_2 on geological formations, and (c) the consequences that derive from the displacement of the fluids by the injected CO_2. Therefore, the escape of CO_2 from a storage site into the atmosphere or into the overlying aquifers must be avoided through the analyses of the advection/diffusion processes of CO_2 from the subsoil.

The study of natural analogues, such as cave systems, offers a valuable opportunity to investigate the dynamic of this trace gas within the karst critical zone, its preferential migration pathways and the long-term impacts associated with its potential loss from geological storage. The challenges that cave monitoring could address are: (1) the study of the carbon cycle in the Earth Critical Zone as a potential natural carbon sink or source, (2) the improvement of knowledge of CO_2 migration mechanisms underground and their link with endogenous dynamics (seismicity), and (3) the strengthening of monitoring techniques of CO_2 storage sites in order to promote CCS as a reliable solution to contribute to the mitigation of the effects of GHGs on global changes.

This study explores cave monitoring techniques for modelling carbon flux at the geosphere-atmosphere interface based on data provided by a continuous measurement system optimized for recording underground anomalous high level of carbon dioxide concentrations installed in a natural analogues in NW Sardinia (Italy), a karst area that hosts one of the Italian monitoring points of the ICOS infrastructure and where the carbon budget and its dynamic has not been sufficiently addressed by the global carbon cycle models.

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The WoKaS-Iso Database: Workflow for a Global Compilation of d18O and d2H Records in Cave Drip Water and Karst Springs for Enhanced Understanding of Karst Systems

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Abstract

For analysing karst hydrogeological systems, karst springs and cave drip observations emerge as indispensable components. The stable isotope records from them can improve understanding of vadose and groundwater systems, supporting modelling. However, the limitations arising from the constrained accessibility and high costs of time series measurements of stable isotopes in karst aquifers have hindered progress in karst research and impeded the accurate understanding of karst processes in comparative or large-scale studies. Therefore, there is a pressing need to compile these valuable data from existing studies on a global scale. In this study, we present the workflow to compile the WoKaS-Iso database, an extensive collection of time series data for d 18O and d2H isotopes in karst springs and cave drip water from diverse sources, encompassing publications, theses, reports, online archives, and collaborative initiatives worldwide. The database incorporates data sourced from 194 springs and 79 caves, comprising 290 time series for springs and 596 time series for cave drip water. These datasets provide coverage across significant karst regions globally, spanning China, the USA, Europe, the Middle East, and Australia. Within datasets, 81% for springs and 67% for cave drip water exhibit resolutions less than monthly intervals. In addition, by integrating isotopic records with associated environmental parameters, including spring discharge, drip rate, precipitation, and rainwater isotopes, the database offers a comprehensive perspective on hydrological behaviours in karst aquifers and enhance the ability of advancing hydrogeological modelling. The WoKaS-Iso database not only deepens the understanding of the complex systems but also promotes sustainable water resource management as well as the potential to foster collaborative research. This initiative also fits the goals of the next phase of the upcoming SISAL (Speleothem Isotope Synthesis and Analysis) project. The SISAL working group aims to create a detailed collection of speleothem isotope records to aid climate reconstruction and model evaluation, providing a robust framework that can be readily applied and adopted for the development of a specialized karst database.

Keywords: WoKas_Iso database, stable isotopes, karst springs, cave drip water, SISAL working group

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Transfer of meteorological signals through an autogenic recharge karst system: the Corchia Cave (Apuan Alps, Central Italy)

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Abstract

Karst systems heterogeneity causes the modification of the recharge (i.e., precipitation) in terms of physico-chemical properties, from infiltration through the vadose zone first, and then the phreatic zone. Consequently, the water discharged by karst springs shows properties that depend on the aquifer architecture and flow dynamics. To unravel how vadose and phreatic flow dynamics modify recharge, two monitoring stations of water level (Lw), temperature (Tw), and electrical conductivity (ECw) were installed in the Corchia cave system (Apuan Alps, Italy). One station was placed along the Vidal vadose stream (V), whereas the other one was installed at the Fontanacce di Cardoso spring (C), which is the sole source of the Corchia system (about 3 km SE from the deepest explored cave passage). The monitoring lasted for two years and the responses of the two flows to recharge (rainstorms, snowmelting) were compared. Tw varied from 6.86 to 7.87 ∘C at the Vidal stream station (V), whereas it ranged between 9.54 and 12.99 ∘C at the Cardoso spring (C). ECw varied in the ranges of 117-234 and 130-268 μS/cm at V and C, respectively. Both V and C showed dilution as prevalent response to infiltration, however small-scale piston episodes occurred in the Vidal stream (V) during storm hydrograph rising limbs. Overall, V physico-chemical properties showed the contribution of multiple vadose tributaries, whereas C exhibited trends that are caused by a phreatic zone that quickly transfers infiltrating water to the source with poor homogenization. The quick transfer of water through the phreatic zone was revealed also by the storm hydrograph lag analysis. A mean lag (dts) of 2.31 h was observed between the precipitation onset and the Lw increase for V, whereas dts had a mean value of 4.5 h for C. The lag between the precipitation peak and the Lw peak showed mean values of 4.2 and 8.2 h for V and C, respectively. The lags of the onset of Tw variation between V and C varied from − 0.25 h to 33 h, with a mean value of 8.3 h. The Tw peaks observed at C occurred between 1.5 and 64 h (mean = 17.2 h) after Vidal Tw peaks. The lags of the onset of ECw variation between V and C varied from 1.25 h to 19.25 h with a mean value of 7.1 h. ECw peaks at C happened between -1.25 and 24.8 h (mean = 10.6 h) after the ECw peaks of V. This study demonstrated that autogenic recharge is transferred quickly through the about 1000 m-thick vadose zone to the phreatic zone and finally to the outflow. This fast transfer allows only a weak modification of the infiltrating water physico-chemical properties which can be clearly recognized at the karst spring. Just a few studies dealt with the simultaneous monitoring of vadose and phreatic flows and their physico-chemical properties. The Corchia Cave represents an ideal test site among alpine karst systems due its well-constrained hydrogeological structure and more than 30 years of investigation.

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TOPIC 4
Cave monitoring and management
POSTERS

An integrated monitoring system in the karst system of Monte Cucco Cave and the Scirca spring (Central Italy)

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Abstract

The Monte Cucco Cave is the deepest and longest karst cave in the Umbria-Marche Apennines. Its passages, surveyed for more than 30 km, provide an extraordinary opportunity to observe the water path from the infiltration zone to the water table, which feeds numerous springs also exploited for drinking water purposes. The Scirca spring is the main one, supplying an average annual discharge of more than 200 l/s. At the cave bottom, at the terminal siphon of Franco pit, 917m below the surface, speleologists have measured fluctuations of phreatic level as high as 100m, depending on both season and cumulated rainfalls. The project aims to extend the monitoring of this karst aquifer, to increase the knowledge on the groundwater circulation dynamics, and to allow to develop reliable hydrodynamic models for water resource management. A monitoring system was implemented, including a weather station at the main cave entrance and an infrastructure located at the cave bottom. This monitoring system will integrate the existing network, which includes a weather station near the Scirca spring and a monitoring system acquiring its discharge data. Both infrastructures will synchronize data acquisition with identical time scans.

The infrastructure, which will gather data on groundwater levels, temperature, and conductivity, has been designed to gather data for at least 8 years. Its remote position at the bottom of the cave does not allow direct data download from outside, so a storage system will be located within the cave, and speleologists will reach it on a six-monthly basis to download the data.

The project aims to promote productive collaboration between sectors which usually interact only marginally, making easier the transfer of knowledge between water managers and speleologists who, with a scientific exploration approach, have gathered a unique and

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invaluable wealth of information about the cave system.

Furthermore, the collected data will be shared with several institutions involved in water resource management, optimization, and study (Umbra Acque S.p.A. , Regional Agency for the Environmental Protection ARPA, Earth and Environmental Sciences Department at the University of Bari Aldo Moro, Physics and Geology Department at the University of Perugia, National Research Council CNR) for analysis and interpretation under an Open Data license (https://www.dati.gov.it/content/italian-open-data-license-v20).

Hydroclimatic study of a coastal karst for archaeological conservation: the case of the Cosquer cave (SE France)

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Abstract

The conservation of paleolithic wall paintings and engravings in decorated caves is dependent on the air and water flows in the karstic network and through the host rock. Usual main dangers linked to hydroclimatic conditions are due to calcite precipitation or rock alteration, drying out of the walls and disintegration, biological colonization, groundwater flow. In a coastal karst in which the cave is connected to the sea, the seawater represents an extra cause of danger. First the seawater level fluctuations can flood the decorated wall, by daily tidal variations, storm events or long-term rising with climate change. Second, the temperature of the intruded seawater can also be a source of heat in the cave with rapid variations in relation with the oceanographic and atmospheric conditions, that modifies the internal airflows.

We present the case study of the Paleolithic decorated "Cosquer cave" (SE France), located in a partially drowned coastal karst linked to the sea. Pools cover nearly half of the cave's surface and are filled with seawater continuously renewed. The goal of this study is first to show how hydroclimatic data are used to explain the pools water level variations, and the airflows through the rock surrounding the cave and inside the cave. Then, the results are associated with different risk factors for the conservation of the wall art.

Hydroclimatic monitoring has been carried out since 2014 and enhanced in 2023 with extra air temperature probes. Data shows that cave air pressure is nearly always higher than the atmospheric pressure, consequently pools water level is below the sea level. The air in the cave is confined by the low permeability host rock and seawater filling the submarine karst network. However, from fall to spring seasons, outside air flows in the cave through shallow submarine karstic conduits during pressurization events. During summer air pressure slowly decreases as air flows out the cave through the host rock. Air and water temperatures vary seasonally, but can also drop occasionally under windy conditions. Temperature gradients measured at several elevations demonstrate strong convection phenomena in the cave.

We deduce the following conservation lessons: The pressurization mechanism temporarily preserves arts close to pool's water level. The summer rise of the water level is a threat for

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the art close to the pools, but as it is reproductible from year to year we elaborated a tool to predict the maximal water level at the end of summer. The possibility of a dramatic increase in the rock's permeability caused by conduit openings in the massif is also a concern, as it would stop the cave's overpressure. Last but not least, temperatures are used to determine the hydroclimatic conditions most likely to cause condensation or evaporation on the walls. All these results should alert cave managers to conservation risks and assist them in defining appropriate conservation strategies.

This study is an example of interdisciplinary work bringing together physics, challenges of archaeological conservation and assistance to managers of the Cosquer cave, that could also benefit to managers of other sites.

Identifying CO2 sources in caves during short-term ventilation events using peak detection analysis

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Abstract

Short-term ventilation in caves, characterized by the temporary and swift exchange of air between the cave's internal atmosphere and the external environment, is a critical aspect of cave studies. Understanding these short-term events allows us to comprehend the dynamic relationship between the external atmosphere, the cave, and the vadose zone, impacting cave ecosystems and the preservation conditions of geological formations, particularly delicate structures like speleothems. Continuous monitoring of environmental parameters, such as temperature, humidity, wind, and trace gases (i.e., CO2, 222Rn, CH4), is essential for achieving this understanding.

CO2 holds particular significance within cave ecosystems as it plays a direct role in essential karst processes like the dissolution and precipitation of carbonate minerals. In this context, the cave atmosphere comprises various sources of CO2, including its production in the soil and vadose zone through root respiration and organic matter decomposition, which then advects or diffuses into the cave environment. CO2 may originate from the exhalations of visitors in show caves and from atmospheric CO2 entering caves due to ventilation processes. The contribution of different CO2 sources to the cave atmosphere can be quantified through the isotopic C signature of the cave air; and cave air composition varies throughout the year, on a seasonal, diurnal, and hourly scale. Characterizing hourly variations presents a difficulty given the complexities involved in capturing and analyzing rapidly changing environmental conditions, potential fluctuations in human activity, and limitations in data resolution at such fine temporal scales. In this regard, the sheer volume of generated data can also pose challenges in terms of handling and analysis.

In this study, we investigate short-term events, ranging from hourly to several days, using CO2 and stable carbon isotope of CO2 data obtained by a CRDS (Cavity Ring-Down Spectroscopy) CO2 and CH4 carbon isotope analyzer installed within Nerja Cave (Malaga, Spain), providing readings every two seconds. The cave air is sequentially pumped during one hour in four different halls of the cave: two situated in the tourist sector and two in the non-tourist sector. We employ peak detection analysis to identify and characterize significant peaks in the dataset throughout an annual cycle, including winter, summer and the most complex transitional ventilation regimes: autumn and spring. These peaks may signify important events, such as sudden changes in temperature or spikes in CO2 concentration from different sources, often with similar isotopic compositions (i.e., vadose CO2 and human

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breath). Following peak detection analysis, specific events are subsetted, and CO2 sources are attributed to these events. Although the isotopic differences between sources can be subtle, integrating peak detection and the source attribution method provides a comprehensive understanding of the short-term dynamics of CO2 in caves, offering insights into the intricate interplay between natural processes and human influences in these delicate ecosystems.

Keywords: CO2, isotopes, peak detection, source attribution, short term events, ventilation

Spatio-temporal variability of Carbon dioxide in the Sant Josep Cave, la Vall d'Uixó, Castellón, Spain

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Abstract

Caves are a stable geological system but they are easily influenced by changes in their environmental characteristics. Carbon dioxide (CO2) concentration plays an important role in karst processes, influencing both the deposition and dissolution of carbonates. Furthermore, CO2 is a key microclimatic parameter that reflects variations within cave environments. Spatial and temporal variations of CO2 concentrations could be attributed to various factors, with visitors having a particularly significant impact in show caves. In the Sant Josep Cave, a significant notable spatial and temporal variation in CO2 concentration between summer and winter has been observed in 2022-2023. Temporally, maximum values were observed between June and September (with peaks of 9000 ppmv CO2 in the Dry Gallery and Last Pier) and minimum values between November and February (with peaks of 1500v ppmv CO2 in the Dry Gallery and Last Pier). However, the spatial distribution of CO2 in the cave is highly variable. A positive gradient of CO2 concentration was observed during the summer from the entrance of the cave to the end of the tourist sector (15 ppmv/m). Starting from the non-tourist area, the gradient reverses to -10 ppm/m until it stabilizes at 4500 ppmv. In winter, the general model of spatial distribution is similar, although the gradient is reduced to 2 ppmv/m from entrance of the cave and reverses to -7 ppmv/m from the initial sector of the non-visitable area. The spatial model of CO2 concentration shows three well-differentiated areas; A) Entrance to Siphons sector, B) Final Siphons sectors-Dry Gallery to Last Pier and C) non-visitable area. The temporal variation in CO2 concentration seems to be influenced; on one hand, by low ventilation in summer that prevents the effective movement of gases between the atmosphere of the Earth and the cave atmosphere. On the other hand, the greater number of visitors increases CO2 concentration in the cave. It is possible that microbial and plant activity play an important role in the increase of CO2. The ventilation of the cave could be influenced by seasonal temperature differences and changes in atmospheric pressure, with notable ventilation in winter and inefficient during summer. These factors could be modulated by the geometry of the cave passages, which determines the spatial distribution model of CO2 concentration in the Sant Josep Cave. In this sense, it is possible for a sealing effect to occur in the galleries developed between two siphoned zones (Final Siphons Sector and Non-visitable Zone). This phenomenon explains the occurrence of extreme CO2 values and the reversed gradient from the end of the tourist zone. they are

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Keywords: carbon dioxide, cave ventilation, show cave, visitor

TOPIC 5
Karst groundwater dependent ecosystem
ORAL PRESENTATIONS

Global estimation of drainage characteristics in karst landscapes

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Abstract

Hydrological modelling constitutes an important tool in the field of karst water resource management. However, the modelling of karst systems often poses a challenge due to their strong subsurface hydraulic heterogeneity and the lack of large-scale karst catchment data availability. Spring hydrograph recession analysis is a method commonly used to derive information regarding the hydraulic dynamics of karst systems; particularly the slow and quick flow recession parameters are valuable for the parameterization of karst hydrological models. Regionalization procedures allow the projection of karst spring hydrograph recession parameters from gauged to ungauged karst catchments. So far, large-scale hydrological models barely consider the complexity of karst processes which result in unreliable estimations within karst regions. To fill this gap of global parameter regionalization in karstic landscapes, we took advantage of a newly developed automated karst recession analysis tool and the availability of large climatic and physiographic datasets. With the application of a regression-based regionalization model, this study estimates global slow and quick flow parameters from climatic and physiographic predictors in karstic landscapes. By focusing on the ratio of quick and slow flow parameters, that we define as Karstification Index (KI), we were able to globally identify regions with higher and lower degrees of karstification. Our analysis shows that different metrics derived from drainage density are the most powerful predictors of KI, especially in combination with selected climate metrics. With that, we obtain high agreement ($R^2 \geq 0.8$) of predicted and observed KI across European karst systems. To the best of our knowledge, this study is the first to estimate slow and quick flow recession parameters in karst landscapes across such large scales. The global estimation of KI will improve the global karst water resource management by improving the parameterization and consideration of karst processes in large-scale hydrological models. Ultimately, our research contributes to a more accurate representation of karst aquifers on a global scale.

Keywords: karst hydrological model, machine learning, random forest, regionalization, parameterization, karstification, modelling

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MONITORING OF HYDROGEOCHEMISTRY AND HYDROLOGICAL ISOTOPES IN KARST SPRINGS OF TEZBENT PLATEAU, TEBESSA REGION, NORTHEAST OF ALGERIA

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Abstract

Karst springs of the Tezbent plateau were studied to get more insight into the hydrogeo-logic, and hydrodynamic behavior of this karstic system. Four springs were studied in terms of hydrogeochemical constituents as well as δ18O and δ2H during September 2021 to June 2022. Tezbent mountain range, northeast of Algeria, drains carbonate aquifers through some important karst springs.

The physical and chemical characteristics of water samples were studied in order to assess the origin of groundwater and determine the factors driving the geochemical composition. The ionic speciation and mineral dissolution/precipitation was calculated. The main factors controlling the groundwater composition and its seasonal variations are the geology, because of the presence of carbonate formations, the elevation and the rate of karst development. Carbonate chemistry is diagnostic of the effect of karst development. Interaction between groundwater and surrounding host rocks are believed to be the main process responsible for the observed chemical characteristics of groundwater in the study area. The δ18O, δ 2H of the groundwater samples show that the groundwater recharge is of meteoric origin and suggest the absence of the evaporation effect on the isotopic composition.

Keywords: karst springs, hydrochemistry, isotopes, Tezbent, Algeria

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New insights on epigene karst landforms recognition and classification in Central Apennines (Abruzzi, Central Italy)

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Abstract

The Central Apennines are among the significant areas in the panorama of the karst landscape of peninsular Italy and the Abruzzi region is poorly studied in the framework of karst geomorphology, especially for epigene karst in a modern approach based on GIS techniques and remote sensing data. Existing data, in the form of archives, databases and maps, cover only restricted portions of the region and are limited only to specific areas analysed with high detail or to specific topics (mainly hypogene karst, speleological inventories, etc). Moreover, the lack of quantitative data based on morphometric analyses and temporal constraints does not allow to make considerations on the actual karst distribution and on the landscape evolution.

The Abruzzi region is covered by carbonate karst terrains for about 40 % of the total surface, which consist of N-S to NW-SE Jurassic and Cretaceous limestone ridges with elevation ranging from 1000 to over 2900 m a.s.l. These terrains have been classified as carbonate karst morpho-units (CKMU) which are separated by valleys set on Miocene pelitic-arenaceous terrains and by tectonic/tectonic-karstic plains filled by Quaternary continental deposits, both bounded by SW and NE dipping normal faults active from late Pliocene-early Pleistocene to present.

The carbonate karst morpho-units have been characterized through morphometric parameters (elevation, slope, surface curvature, hypsometry, local relief, topographic position index, terrain roughness index), surface hydrography (hydrographic basins and endorheic areas) and carbonate rocks lithofacies (carbonate platform, slope, basin and related transition facies) using a regional 10 m resolution DEM, 1:50.000 to 1:25.000 scale topographic maps and existing geological maps (1:100.000 to 1:50.000 scale).

Within each CKMU, the main types of epigene karst areas were mapped through visual recognition and manual mapping based on the inspection of: 10-to-1-meter DEM; multiscale topographic maps (1:25.000 to 1:5.000 scale); multitemporal and multiscale satellite imagery and aerial photographs; existing geomorphological maps and datasets. These karst areas were classified by morphometric parameters, surface hydrography and carbonate rocks lithofacies allowing a spatial and statistical analysis of the data and the definition of the most representative parameters. Through these parameters other potential karst areas were identified.

Finally, individual epigene karst landforms were mapped integrating: i) a semi-automatic

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[*]Speaker

detection and mapping of closed karst depressions by means of multiband satellite imagery analysis (e.g. VNIR bands, iron oxide index, normalized difference vegetation index and other vegetation indexes) and DEM related methods (i.e. delineation based on the outermost closed contour line, watershed-based doline delineation and filled-DTM based delineation); ii) geomorphological mapping of other karst landforms (e.g. gorges, dry valleys, non-closed depressions, karst mounds) by means of remote detection and field surveys.

This analysis led to: i) an updated and digital map of CKMU and karst areas of the entire Abruzzi region at 1:100.000 scale; ii) the classification of each CKMU and main karst areas through morphometric, hydrographic and lithological parameters; iii) a new integrated mapping of epigene karst landforms (semi-automatic detection and geomorphological mapping) of the Abruzzi region.

Past and current conditions driving the distribution and the ecology of cave-dwelling crustacean isopods

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Abstract

Subterranean environments and caves host a wide variety of highly adapted endemic species that are vulnerable to disturbances and environmental changes but are poorly understood, especially for the conditions, past and current, that affect their distribution. Do the current ecological conditions weigh on the distribution of subterranean organisms, or do the palaeogeographic history have far greater importance? The aim of this study is to identify the factors related to habitat suitability and occurrence of freshwater cave-dwelling isopods of the genus *Monolistra*. This genus lives in the karst areas of the south-eastern Dinarides, through Italy into south-eastern Switzerland, where they inhabit different typologies of groundwater habitats and can represent a significant fraction of the total biomass. For a broad scale analysis, we retrieved occurrences of different *Monolistra* species in Italy for the period 1934-2023, by personal observations and review of academic and grey literature. We performed an a priori choice of environmental variables, selecting the most biologically meaningful for the studied taxon. Species distribution models were built using Maxent to establish relationships between environmental variables and species occurrences. We adopted a spatial cross-validation approach to select the set of environmental variables providing the highest power of predicting distribution outside the calibration range. In order to consider palaeogeographic factors, maps of shorelines during Early (20 Ma), Middle (10 Ma), and Late (8 Ma) Miocene and maps of ice extent during the Last Glacial Maximum were retrieved. For a microhabitat analysis, we performed extensive and repeated surveys in the westernmost populations of the Italian and Switz ranges of this genus. Occupancy models, within a Bayesian framework, were used to estimate the relationships between environmental covariates, detection probability and occupancy in the surveyed caves. The presence of carbonate rocks strongly drove the habitat suitability, which had as well a positive relationship with vegetation and temperature, and a negative relationship with climatic instability; habitat suitability resulted generally high in all the carbonate Prealps. Detection probability was influenced by hour and date, with higher probabilities in the morning and early summer.

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The plots that were permanent, connected to a larger part of the aquifer and without light from outside had a higher probability to be occupied. The fact the detection probability was influenced by microclimatic conditions suggests sensitivity to small variations in the generally constant cave climate. Our results show that current ecological conditions strongly affect freshwater cave-dwelling isopods, both at a broad scale and at the microhabitat scale, with their distribution shaped by current conditions and by palaeogeographic history, including survival in glacial refugia. The study of endemic species in caves is of great significance: with climate change modifying Earth's ecosystems, these unique organisms face new challenges, and investigating their responses to environmental shifts provides crucial insights into the adaptations of these species and tools for their conservation. Moreover, they could represent good proxy for the assessment of the impacts of climate change on the whole karst ecosystem and a biological indicator for the conservation of this environment.

Keywords: biogeography, detection probability, species distribution models, palaeogeography

Stable isotope properties of the dripwaters in the caves of the Moravian Karst (Czech Republic)

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Abstract

The study in the Amatérská Cave (Moravian Karst) in the Czech Republic from August 2020 to January 2023 focused on isotopic analyses of cave and precipitation waters to understand the evolution of the hydrological season. Six sampling sites were chosen – five dripwaters (E, K, M, N, and R) and a pool (J), and a total of 127 samples were collected. In addition, rainfall precipitation was sampled (23 samples) in a garden in a nearby village Olomučany, as the isotopic composition of precipitation was essential for assessing the evolution of cave waters.

Precipitation data revealed a mean composition of $\delta18O = -8.9\pm3.8$ and $\delta D = -62.6\pm30.6$ after averaging monthly data. In addition, precipitation showed a slightly higher mean composition and a significantly broader range of values than cave waters, aligning with groundwater development mechanisms that homogenize and attenuate isotopic signals during passage through geological formations. A local meteoric water line for Olomučany (O-LMWL) $\delta D = 7.84\times\delta18O + 7.67$ was constructed based on precipitation data, deviating slightly from the global meteoric water line (GMWL).

Three groups of cave drip waters were identified based on isotopic composition, suggesting similar or related water sources.

The first group (drip E) deviated significantly from O-LMWL, being the heaviest. The second group (drips N and R) aligned with O-LMWL, with drip N showing higher variability. The last group (drips K and M) exhibited slight isotopic differences, laying on the local meteoric water line. Pool J, located in the cave corridor between drips K and M, displayed higher variability, partially deviating above O-LMWL and overlapping with the third group. Seasonal differences in isotopic composition provided insight into the water residence time. The drips K, N, and pool J exhibited seasonality. The drip K samples showed the lightest isotopic composition samples in spring and the heaviest at the end of summer. The drip N had the lightest samples in winter and heaviest in August. The pool J showed the most significant isotopic range, with lighter samples in winter and heaviest in spring 2022, suggesting influences like pool water level variations, contributions from other sources (similar to group 2) during wetter periods, and fractionation caused by evaporation of lighter molecules into the cave atmosphere. In addition, the collected isotopic dataset was compared with previous studies in Moravian Karst, revealing broader insights into the isotopic evolution of cave waters, their connection to external precipitation, water sources, and the local karst hydrology.

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Keywords: stable isotopes, Moravian Karst, dripwater, isotopic composition, precipitation

TOPIC 5
Karst groundwater dependent ecosystem
POSTERS

Degradation phenomena in karstic groundwater resources of central Greece

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Abstract

In Thessaly, central Greece, the existence of wide carbonate aquifers favours the underground storage of huge amounts of water resources. The social and economic development of the last century caused the increase of productive activities requiring progressively greater amounts of water. As both direct and indirect consequences, the quality and quantity of the natural water reservoirs is increasingly suffering a general degradation. During the last years, the climatic changes, occurring at the global scale and particularly within the Mediterranean realm, are responsible for the decrease of the mean annual precipitations and their concentration during the hydrological year. Moreover, a general increase of the temperatures further contributed to quantitatively waning the groundwater resources. It is obvious that the combined causes, both climatic and anthropogenic, have strongly contributed to the impoverishment of the hydrodynamic equilibrium of the underground water resources.
In the eastern Thessaly plain, the alluvial aquifer systems are mainly fed by the surrounding karstic massifs. The overexploitation of the last few decades has caused a decrease of the piezometric level exceeding 80 m, but especially the anthropogenic activities have largely exceeded the capacity of the aquifers to regenerate themselves. This in turn has caused strong consequences for the natural ecosystems. Beyond the progressive drying up and/or reduction of the karst springs discharge, typical environmental problems which have been induced include the frequent formation of ground fissures and localized land subsidence generating extensive damage to buildings and infrastructures. In order to restore the water balance and to reverse the environmental degradation, an artificial reservoir was restored in correspondence of the former Karla lake.
In this framework, the present research is an attempt to separate and quantify the role played by the climatic changes and by the human activities on the hydrogeological equilibrium of two major karstic aquifers discharged through two major springs, the Yperia Krini and Mati Tirnavou (discharge about 2.6 m3/s) both in Eastern Thessaly and well known since Antiquity. In particular the statistical elaboration of the precipitation time series integrated with geological, stratigraphic, hydrogeological data and demographic data allowed to define: a) the hydrogeological model and the principal hydrodynamic parameters of the examined karstic systems; b) the hydrodynamic behaviour of each carbonate system in different feeding conditions; c) the relationships between the active recharge of the springs versus the precipitation trend; and finally, d) the influence of the human activities in the quantitative degradation of the carbonate systems.

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Hydrogeological characterization of the San Giovanni spring (Castelluccio Inferiore, Basilicata region)

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Abstract

The main aim of this study is to identify strategic groundwater resources belonging to the hydrostructure of the northern sector of Lauria Mountains; in particular, the groundwater of the La Spina - Zaccana Mounts limestone-dolomite aquifer, to allocate for drinking water supply during water emergency conditions. The aquifer under study lies in the north-eastern portion of the Lauria Mountains hydrostructure, between 1652 m (La Spina Mount) and 506 m a.s.l. (San Giovanni spring), and is drained from the San Giovanni spring front; minor springs are scattered at the edges of the hydrostructure and characterized by limited shallow groundwater flow path.

The in situ geological and hydrogeological surveys, still in progress, make evident that the limestone-dolomite lithologies are characterized by intensely fractured steep slopes, locally affected by karst morphologies, particularly present along the Zaccana Mount northern and southern slopes and in the spring emergencies area, characterized by high permeability. The dolomitic limestones show very fissured and karstified features, interstratal karst cavities are also frequently present mainly in the western portion of the San Giovanni spring.

The investigations carried out highlight that the aquifer geometry, the groundwater circulation and the groundwater emergencies are closely connected to the geostructural and karst arrangement. The structural elements present in the hydrostructure, such as faults, tectonic contacts, rock fissuring and fracturing and karst evidences, define deep groundwater flow, determining specific hydrodynamic characteristics of the spring. The Castelluccio Fault constitutes the morphostructural southern limit of the hydrostructure and represents the superimposed permeability threshold of the San Giovanni spring front.

The groundwater flow, predominantly in the NW-SE direction, feeds the several emergencies of the San Giovanni located along a steep slope between 480 m and 504 m a.s.l., with the discharge rate of around 550 l/s, of which only around 150 l/s are used for drinking purposes. The remaining rate is not captured and could be utilized as strategic groundwater resources.

Keywords: Hydrogeology, hydrostructure, San Giovanni spring

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Main characteristics of largest karst springs of Albania

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Abstract

The total surface of Albania reaches 28,748 km2 and the population 3.2 million. In Albania karst rocks cover about 6750 km2 consisting 25 independent karst massifs (regions). Among them, the 23 consisting of carbonate rocks cover a total surface of 6500 km2 , while two regions with a total surface of 260 km2 , consist of gypsum. High-elevation carbonate mountains facilitate the formation of high hydraulic gradients, often creating welldeveloped conduits ending in low-elevation large springs. In the hydrogeological map of Albania scale 1:200.000, published in 1985 are shown about 2000 karst springs varying greatly in productivity. Among them 110 karst springs have been mapped with an average discharge higher than 100 l/s, and with 17 of them showing discharges higher than 1000 l/s. The average discharge of the Blue Eye, the largest spring of Albania is 18.4 m3 /s. Regarding their quality, most of karst spring of Albania are fresh (drinkable), some of them issuing from the two gypsum regions are salty, some springs located in the south Albanian karst coastal line are salty and some important springs are thermal and used in balneology. The presentation will be focused on the description of some among the most important springs as regard their discharge, aesthetic and economic values, as well as the origin. Some springs issue from syphons at depths ranging from some tens of meters to more than 100 m; some are transboundary springs. There are also springs which in high percentages are recharged by the surface water (lake and rivers), or formed from seepage of groundwaters of other aquifers (intergranular). Some big karst springs are used for urban water supply, for the production of electricity, as well as for irrigation. Some big karst springs with very particular aesthetic values, like Blue Eye Spring, serves as touristic attraction For their investigation and estimation different methods ate used, allowing their quantitative and qualitative estimation; based upon our experience, as shown also for basin wide investigation, the most productive methods are the environmental chemistry and the use of isotope. Some of the most important karst springs of Albania are also included in the project MIKAS of the IAH Karst Commission.

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*Speaker

Medieval system of Managed Aquifer Recharge in karstic aquifers: The case of the Acequia de Yegen (Sierra Nevada, Spain)

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Abstract

Artificial groundwater recharge is a core strategy of adaptation to water scarcity in the Sierra Nevada mountain range in Southern Spain since at least the Islamic period (VIII-XV centuries). The practice is based upon the so-called "acequias de careo", which are channels that are used to divert water from headwater streams during peak flow periods, usually spring snowmelt, to infiltrate it along the steep slopes of the mountain range. By that, the local communities enhance groundwater discharge from the sloping aquifers of the area and extend it over longer time periods, which is crucial for meeting higher water demands along the hot and dry summer months. Proof for its effectiveness is not only the survival of this ancient practice, but also its astonishing expansion with more than 700 km of careo channels all over the Sierra Nevada.

In recent years, considerable scientific effort has been made to better understand the effects of acequias de careo on the regulation of water resources in slope aquifers of the Sierra Nevada, especially in weathered and fractured low-conductivity schists of the Nevado-Filábride Complex, which cover the entire mountain range. However, only little work has been done on careo channels that infiltrate water close to or directly into the carbonates of the Alpujárride Complex, which surround Sierra Nevada at its fringes forming important local and regional aquifer bodies.

Here we add new insights by comparing spring response in the schistous and karstic environment connected to careo aquifer recharge. For this purpose we are studying the Yegen careo channel, which is an inter-basin channel that is used to transport water along 6 km all year round, from the Mecina river basin in the Central Alpujarras to the neighbouring community of Yegen. The transferred water either serves directly to irrigate crops on the

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slopes above the village of Yegen or to recharge the aquifer at the final stretch of the channel (ca. 1600 m a.s.l.) during winter and spring, when irrigation demands are lowest.

In this study, streamflow and physical-chemical data were collected during one hydrological year (2022/23) in the Yegen channel and from two springs, one of which is emerging from schistous materials (1375 m a.s.l.) and the other from metamorphic limestones (1067 m a.s.l.). Furthermore, we compare major ion and water-stable isotope content of spring and careo channel waters to unravel the role of the Yegen channel to sustain water availability from both springs, which are, in fact, the only potable water supply to around 364 inhabitants of Yegen (INE, 2022).

Our preliminary results confirm the connection between careo recharge and karstic spring discharge, which behaves differently from spring discharge in schists. Moreover, written evidence on this inter-basin water share in the XVI century (Libros de Apeo y Repartimiento, 1572) is highlighting the importance of the Yegen channel. In this sense, traditional water management practices, like the nature-based solution presented here, have proven to work for centuries and may offer inspiration for future adaptation measures in times of climate change.

Keywords: managed aquifer recharge, inter basin water transfer, traditional ecological knowledge, semi arid mountains, acequias de careo, water sowing and harvesting

Photo: Giovanni Giuliani