CENTRE FOR KARST HYDROGEOLOGY

BOOK OF ABSTRACTS
of
VIRTUAL MULTIDISCIPLINARY CONFERENCE

FROM TOP

KARST 2021

TO BOTTOM

6 June 2021
Belgrade

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Book of Abstracts of the Virtual Multidisciplinary Conference
for karst researchers and professionals
6 June 2021

"Karst: From Top to Bottom"

Editors
Zoran Stevanović & Saša Milanović

The International Year of Caves and Karst

Centre for Karst Hydrogeology

Belgrade, 2021

Pobednik (The Victor) is a monument in the Upper Town of the Belgrade Fortress, on top of the Miocene limestones
(Photo: Veljko Marinović)

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INTRODUCTION

Karst environments has intrigued scientists, engineers, and ordinary people alike for millennia due to its many fascinating facets. It feeds the world's largest springs; it represents one of the first human habitat in history; it possesses some mysterious elements in the world of caves; it supports living creatures often unique to specific locations; it behaves unpredictably; and it is extremely vulnerable to both natural and anthropogenic contamination.

The aim of this multidisciplinary conference was to provide space for both, the academic students, and the working professionals, to present results of their challenging work in the karst environments.

Prior the conference a special thematic session *"Lecturing by Distinguished Guests"* with online presentations of 12 invited eminent karst experts (*Augusto Auler, Jianhua Cao, Francesco Fiorillo, Derek Ford, Nico Goldscheider, Chris Groves, John Gunn, Hervé Jourde, Attila Kovács, Peter Malik, Bartolomé Andreo Navarro, Abe Springer*) took place on Zoom platform on 5 June 2021 starting from 10 AM (CET).

Virtual multidisciplinary Conference took place on **Zoom platform** on 6 June 2021.

This Virtual Multidisciplinary Conference was one of the activities of *the International Year of Caves and Karst* and was especially devoted to younger and talented karst researchers, preferably, but not limited for age under 40.

The three CO - Thematic areas of the Conference "*Karst: From Top to Bottom*" were:
- ➢ *Correlation* – Water cycle in karst, groundwater genesis, flow paths, hydrodynamic and modelling.
- ➢ *Coordination* – Water management, engineering in karst, threats, contamination and protection of environment and groundwater in karst, monitoring.
- ➢ *Cohabitation* – Geodiversity and biodiversity, speleology and show caves.

Organizer
Centre for Karst Hydrogeology, Department of Hydrogeology, Faculty of Mining & Geology, University of Belgrade
http://www.karst.edu.rs/en/index.html

The event is supported by the UNESCO-IHP, Regional Waterworks of Montenegro Coast, City of Trebinje, Hydro Power System "Trebišnjica", Geological Survey of Montenegro, Geological Survey of Republic of Srpska, Bosnia & Herzegovina, Northern Arizona University, Edwards Aquifer (TX), The National Committee of IAH for Serbia and the KARMA project.
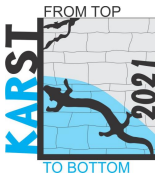
Online Multidisciplinary Conference

"Karst: From Top to Bottom"

Belgrade 2021

ABSTRACTS

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SOURCE APPORTIONMENT OF HUMAN WASTEWATER CONTAMINATION IMPACTS ON KARST SPRINGS IN IRELAND

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Karst aquifers are extremely complex and challenging to understand, as well as exceptionally vulnerable to pollution. In Ireland, low-lying karst catchments exhibit a lot of surface water – groundwater interactions which makes them very susceptible to direct contamination. Groundwater pollution can be associated with a variety of sources making it a complicated problem to solve. In rural and suburban areas, human wastewater effluent (from on-site domestic wastewater treatment systems) and agricultural sources are generally considered among the most significant threats to groundwater quality. However, significant knowledge gaps exist with respect to linking pollutants with specific origins which is needed in order to quantify the various pollution impacts on karst groundwater resources. Thus, investigations of the occurrence, fate and transport (and transformations, where applicable) of source-specific contaminants are crucial for the protection and management of karst aquifers. It is difficult to distinguish between human wastewater effluent and agricultural pollution impacts on karst aquifers using only traditional water quality parameters or any single environmental tracing method. Hence, the impact of microbial and chemical contaminants of human wastewater origin on groundwater quality must be assessed using a multiple-tracer approach, ideally targeting source-specific tracers. An overview of the results obtained during the research conducted throughout the last several years at nine karst catchments in Ireland using a range of methodologies in order to determine and quantify domestic wastewater pollution impacts on karst springs will be presented. Microbial pollution was assessed using flow cytometric fingerprinting and faecal indicator bacteria, while chemical pollution impact assessment included the analysis of fluorescent whitening compounds (FWCs; well-known indicators of human contamination since their origin is mainly from laundry

detergents), specific anion ratio signatures (Cl/Br), quantification and identification of microplastic particles using Fourier-transform infrared spectroscopy (FTIR), and faecal sterol and stanol profiles and ratios. The results show that detection and quantification of source specific chemicals, microplastic particles, specific anion ratio signatures, and microbial fingerprinting methodologies in parallel can provide sufficient information for decision making processes and adaptive management strategies. Notably, whilst some of the techniques used are not capable of being able to link pollutants directly with any particular pollution source, they can still quantify specific pollutants, in some cases to a very high accuracy, thereby determining the overall impacts of contaminants on groundwater quality at karst springs.

Key words: karst springs, groundwater contamination, chemical and microbial fingerprinting, microplastics, on-site domestic wastewater treatment systems

COMPARISON OF KARST RELIEF DENUDATION USING THE METHOD OF LIMESTONE TABLETS AND IONIC RUNOFF (CASE STUDY JASOV PLATEAU, SLOVAK KARST)

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The experimental area of the Jasov Plateau is the easternmost part of the Slovak Karst. The area as a typical plateau has a well-developed surface and underground karst phenomenon, karst springs are situated mainly around its perimeter at the contact of karst slopes of the plain and non-karstic sediments filling the surrounding basins. The area is built mainly of Wetterstein, Gutenstein, and Waxenec limestones and reaches from altitudes on the southern foothill plateau about 200 m to 741 m in the northern part of the area. The plateau is mostly forested, covered with oak and beech, the typical soil is rendzina, the average amount of precipitation reaches 800-900 mm per year.

Since 2005 we have been performing geomorphological research in the area, since 2013 hydrological monitoring of several springs and since 2016 (2018) also the study of denudation by limestone tablets (in addition to this locality also in the western part of the Slovak Karst). A similar study has not yet been carried out in this area. Although our ionic runoff (IR) measurements are from a different period than limestone tablets denudation, they are sufficient to obtain an initial overview.

In the analysis of ionic runoff (Pulina 1974 method based on TDS and discharge), performed in the years 2013-2016, we included regular measurements with a monthly step at 6 karst springs, while the data included e.g. from the sources of the Slovak Hydro-meteorological Institute. The denudation rate using this method is 40.847 $m^3/km^2/year$ from the Jasov Plateau area (calculated over a specific mass of 2.7 $g/cm3$ is 102.1 $t/km^2/year$). Denudation using limestone tablets was determined on two types of tablets. From 2016 on limestone tablets from the Lipica quarry in Slovenia (Gams method, 1966) and from 2018 on local limestone tablets. The results of the weight analyses are different and based on various rock chemistry a time of

exposure. Denudation to Lipica tablets was 4.78 mg/cm^2/year and to local tablets 3.06 mg/cm^2/year (shorter time of exposure). The average recalculated result is 28.8 t/km^2/year.

Denudation on tablets is 3.5 times lower than the detected denudation from IR. This is a comparable difference with the statements of Droppa (2013) from the area of the Low Tatras (SR), which found 3 times lower data and Gabrovšek (2009) compared to hydrochemical methods 4-5 times lower.

Key words: Slovak karst, denudation rate, limestone tablets method, ionic runoff, karst relief

THE UNIQUENESS OF THE KARST LAKE CHEREK-KEL (BLUE LAKE) IN KABARDINO-BALKARIA (RUSSIA)

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Cherek-Kel (Blue Lake) (Kabardino-Balkaria, Russia) is a unique world object, the deepest karst lake in Russia and the deepest karst-source lake in the world. By some parameters, it has no analogy in the world. One of the features of the lake is the presence of hydrogen sulfide in its waters. It has no surface inflow, is completely fed by karst water and mineralized groundwater. The only one river flows out of the lake. The absolute altitude of the lake's mirror is 805 m, the area is 26130 m^2. The greatest diagonal length is 233 m; maximum width – 146 m.

Together with the Center for Underwater Research of the Russian Geographical Society, over 1350 measurements of various indicators of the lake waters, routine observations of the discharge of the river flowing from the lake, the level and transparency of the waters were carried out. It was found that the pH is closer to neutral, Eh varies from -197 to +75 V, which indicates a change in the ratio of oxygen and hydrogen sulfide concentrations in the lake waters over time. Electrical conductivity, on average, is 1158 μS, TDS varies from 503 to 652 ppm, which indicates a consistent composition of lake waters in depth and area. The transparency of the waters is from 20.3 to 29.5 m. The waters of the lake are sulphate-calcium. The content of sulfate-ion varies from 509.7 to 577.0 mg/dm^3, with the maximum values recorded closer to the daytime surface of the lake, and the minimum – at a depth of 250 m. The average water temperature of the lake surface for the study period (October 2016) was 10.5-11.5℃. The temperature value remains constant with depth at 9.3℃. The average value of the water discharge in the river outflowing from the lake is 67857 m^3/day.

The result of the expedition was the refinement of the morphometric parameters of the lake and the establishment of a new depth – 279 m, which is a geographical discovery. The new shape and size of the lake have been established, which are formed due to the actively occurring processes of dissolution of rocks and collapse of walls in areas with their negative

stratification. A sub-horizontal extension of the lake was discovered, from which, presumably, water flows into the lake.

Based on the results of the research, measures have been developed of the lake protection.

Key words: Cherek-Kel (Blue Lake), karst lake, hypogenic karst

HYDROGEOCHEMISTRY OF MINERAL WATERS FROM DEEP-SEATED JURASSIC KARST AQUIFER IN THE SOUTH MORAVIA – LOWER AUSTRIA REGION

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The South Moravian region of Pasohlávky and the Lower Austrian town of Laa an der Thaya belongs to the areas of intensive use of thermal mineral waters. These mineral waters are extracted from deep-seated aquifer of Jurassic carbonates and are exploited by 1,45 km deep wells Mušov-3G (Pasohlávky) and Laa Thermal Nord 1 (Laa an der Thaya). To determine the origin, genesis and possible flow direction in the Jurassic karst aquifer, the total mineralization (TDS) and chemical composition of water samples from 34 wells reaching the Jurassic aquifer were evaluated. Also, new data about isotopic composition of thermal mineral waters in Jurassic aquifer including the stable isotopes of hydrogen and oxygen were obtained. An important geological feature of the studied region is the Mušov transition zone, which divides the body of Jurassic sediments into two sections – the shallower north-western (carbonate development) and the deeper south-eastern section (pelitic-carbonate development). In the south-eastern section, the TDS values reach 20 to 56 g/L. These are marinogenic, strongly mineralized waters and brines of significant Na-Cl to Na-Ca-Cl type, with very low HCO_3^- ratio. The hydrogeochemistry data indicates that the south-eastern deeper section of Jurassic sediments contains mainly fossil seawater in closed hydrogeological structures with limited connection to the active groundwater flow. On the contrary, the north-western section is characterized by groundwaters of the Na-Cl to Na-HCO_3 type with lower TDS values ranging from 0,5 to 12 g/L. The TDS values increase and the ratio of HCO_3^- ions decrease towards the southern part of the north-western section. The decreasing content of meteoric waters (determine by HCO_3^- ratios) is also indicated by the isotopic composition of the mineral waters from the Laa region, which are significantly isotopically heavier and therefore have a higher content of the primary fossil seawater compared to the mineral waters from the Pasohlávky region, which are isotopically depleted. Comparison of the stable isotope composition of the mineral waters from the Pasohlávky with the

modern precipitation data indicates recharging under colder climate conditions. North-western shallower section of Jurassic aquifer therefore represents semi-open hydrogeological structure with active groundwater flow from NW that leads to intensive dilution of primary fossil seawater with meteoric waters. The results of our study indicate hydrodynamic separation of the Jurassic aquifer into disconnected north-western and south-eastern sections. This study is associated with the project Hydrothermal potential of the area (HTPO, ATCZ167).

Key words: Jurassic karst aquifer, mineral water, hydrogeochemistry, stable isotopes

HYDROGEOCHEMISTRY AND ISOTOPICAL ANALISES OF BARUDAB AND MALUSAN SPRINGS OF NAHAVAND (INTRODUCE ANCIENTS' HOST ROCKS IN SANANDAJ-SIRJAN ZONE IN IRAN)

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Freshwater resources in alluvial aquifer are not sufficient for growing population, water resources in karst due to the high quality of water resources allocated for drinking water. Hydro geochemistry of karst springs of Zagros and Sanandaj zones in Gamasiyab basin (Western Iran) emphases on heavy metal and stable isotopes. Karstic springs of Kiyan, Gamasiab, Kengavarkohne, Faresban, Malusan and Baruodab have multiplier discharge than other springs consumed for agriculture mainly and drinking water too. The research methodology is a field-analytical and laboratory-library that used by Arc GIS, SPSS, PhreeQCorAqQa etc. Physicochemical and measured elements are: fluoride, nitrite, nitrate, sulphate, chlorine, sodium, calcium, water turbidity some of heavy metals and isotopic analysis. The focus of investigation in this study Gamasiab karstic spring because it is one of a biggest karstic spring of Zagros Mountains and origin of the Karkhe River. One of the hypotheses is that the concentration of elements in karst Springs of Sanandaj-Sirjanis is higher than Zagros Karst. For determining of integrated the results of this research, hydrogeochemical studies, geological studies, and available information. The expected results from this project shall enhance the general understanding of this karst water resources that will be useful for the long-term management of the resource as a potable water supply (information on the aquifer vulnerability, possible presence of geogenic contaminants, springs temporal flow regime, etc.).

Keywords: hydrogeochemistry, stable isotopes, karst springs, Zagros and Sanandaj

SPECTRAL CHARACTERISTICS OF DISSOLVED ORGANIC MATTER IN FOOT CAVE AQUIFER SYSTEM OF ZENGPIYAN SITE

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With the acceleration of urbanization, aquifers around cities are polluted to different degrees. Karst aquifers are sensitive and fragile to pollutants. In the karst foot cave system, karst pipes and fissures are distributed in a network, which makes the distribution of pollutants in the aquifer more complex. Dissolved organic matter is an important electron donor and product of pollutant decomposition in aquifers, and its distribution characteristics in karst aquifers have an important effect on pollution control. The spectral characteristics of dissolved organic matter have a fingerprint effect on the source and characteristics of dissolved organic matter. This study takes the foot cave aquifer system of Zengpiyan site as the research object. The spectral characteristics of dissolved organic matter in the polluted karst cavern aquifer system were analyzed to provide a scientific basis for the prevention and control of karst groundwater pollution.

Based on the previous data of geophysical prospecting, drilling and groundwater tracer experiments, water samples in foot cave aquifer system of Zengpiyan site which involved of pipes, fracture and sinkhole were sampled in autumn and winter to scan the three-dimensional fluorescence spectrogram then combined parallel factor analysis to interpret the composition and proportion of dissolved organic matter.

Spectral fingerprint index results showed that the dissolved organic matter in the foot cave aquifer system was endogenous, weak humification and mainly recent autogenesis in whole. But anisotropy was observed at different sampling sites according to its local hydraulic characteristics, redox conditions and medium types. The dissolved organic matter was dominated by endogenous and newly produced, showing weak humification, highly degradation, unstable,

low DOC concentration, relatively weak total fluorescence intensity, significantly increased in protein component and significantly decreased in humus component characteristics in sampling sites of weak development of joints and fissures, strong reduction environment and groundwater retention, which result from intense microbial activities. However, compared with above situation, in the water-bearing media such as karst pipes, hillsides and ponds with good fluidity, the input of exogenous organic matter is easy to be received and migration, the endogenous of dissolved organic matter is slightly weaker, the humification degree, total fluorescence intensity and DOC concentration were relatively high.

Keywords: dissolved organic matter, spectral characteristics, Zengpiyan site

GROUNDWATER GENESIS OF THE KRIVI VIR KARST SYSTEM (EASTERN SERBIA)

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Groundwater genesis, chemical and isotopic composition of groundwater, generally depend on several factors, where most important are precipitation and surface water content, mean residence time, acidity and saturation degree, as well as anthropogenic influence. Significant influence on groundwater genesis and circulation may have hydrogeological barriers, which will create conditions for deep groundwater circulation and prolonged time for water-rock interaction.

Krivi Vir system represent a unique karst system located on Kučaj-Beljanica massif and one of the seven systems isolated according to detailed research conducted within the Kučaj karst massif which belongs to the Carpatho-Balkanides. System consists of two springs, the Crni Timok spring with cold fresh water, while the other the Krivovirska Banjica spring has a subthermal-thermal character of groundwater. For purposes of defining the genesis of groundwater from these two springs, a multiparameter approach has been applied consisting of hydrological, hydrochemical and detailed isotope research methods (stable isotopes ^{18}O, ^{2}H and ^{13}C, as well as radioactive ^{3}H, $^{3}H+^{3}He$ and ^{14}C isotopes).

The results reveal the three zones of karst conduits, where the first circulation zone is characterized by larger channel dimensions where groundwater gravitationally circulates over a period of several days, while the second zone consists of deep siphonal channels, in which the waters reside over five years. The oldest thermal groundwater of the Krivovirska Banjica spring, with temperature of 23.4°C, dominantly is discharging in the summer period, when pressure of younger and fresh water is significantly reduced. This represent the third zone of karst conduits, very deep siphonal circulation and the time that this water spends in the underground is 432 years, which makes this water the youngest thermal water within Kučaj- massif.

Key words: karst systems, isotopes, groundwater genesis

HYDRO-ECOLOGICAL PROCESSES OF HYPORHEIC ZONE IN A KARST SPRING-FED POOL: EFFECTS OF GROUNDWATER DECLINE AND RIVER BACKFLOW

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Karst springs constitute an important water resource. Their aquatic environment, however, is susceptible to degradation due to the presence of karst conduit that can deliver pollutants rapidly to the groundwater. This investigation is a case study of a spring-fed pool that is affected by a river. Hydrological, hydrochemical, and biological approaches were used to reveal the characteristics and consequences of the interaction between the groundwater of karst springs and the surface water. During the rainy seasons, the river backflow effect causes the spring-fed pool to form a hyporheic zone that is sensitive to hydrological and hydrochemical processes. Under forward flow conditions, the physicochemical parameters of groundwater at the spring-fed pool exhibited gradient variations in longitudinal flow direction and changed with depth. The threshold value of river backflow into the pool is 99 m (masl). In 2017, the water level of the pool ranged from 96 to 100 m during the high-flow period, which was 1 to 5 meters higher than those in the low-flow period. One to several times a year of river backflow ultimately leads to the death of submerged plants at the spring-fed pool, followed by phytoplankton blooms. Chlorophyll-a (Chl-a) concentration of groundwater was 16 times higher in regions with the slow flow than in those with the quick flow, and Chl-a concentration was higher in the bottom layer than in the surface layer. E. coli in groundwater was affected by the hyporheic zone and downstream rivers and E. coli counts were associated with hydrodynamic conditions. Due to the reduced upstream discharge and the increased amount of water consumption, the frequency and intensity of river backflow increase, leading to a weakening of the hydrological and biological functions in the hyporheic zone. The presence of the hyporheic zone makes possible the transport of pollutants, microorganisms, and plankton to upstream springs via the reverse flow of downstream rivers. We recommend that the effects of hyporheic zones be

considered when classifying sanitary protection zones in the karst water system.

Key words: karst spring; hyporheic zone; river backflow; E. coli; drinking water source

CLIMATE CHANGE EFFECTS ON GROUNDWATER RESOURCES, CASE STUDY: RIJEKA CRNOJEVIĆA

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Climate change issue is high on political agenda of the global community. The problems of more frequent droughts are opposed by periods of uncontrolled flooding, while countries in the coastal areas have long been struggling with the influx of sea water and rising sea levels. Effects of climate change are complex and far-reaching, so numerous global initiatives have been formed to respond to these threats. Even though regulations in the field of climate change generally treat them as result of human activities, climate changed during the Earth's evolution and caused the extinction and evolution of various species on the planet. Groundwater resources, as part of the hydrological cycle are also affected by climate change. As the water supply of Montenegro is based on use of groundwater, more attention is paid to the sustainability of this resource for the coming centuries. Furthermore, attention is paid to the role of groundwater in flooding of certain areas, but also in maintaining the ecological minimum in rivers during drought when it often happens that the direction of flow changes and groundwater begins to feed the surface flow. In case of karst areas, which cover more than 60% of the entire territory of Montenegro, this usually means direct drying of the riverbed. Therefore, the methodology for assessing climate change influence on karst groundwater was developed for the case study located in the Crnojevića river catchment area. As regards to climate projections CORDEX data for 6 driving models on EUR-11 scale was collected. The specific data covers daily projections of surface air temperature (°C), precipitation (mm) and relative humidity (%) until the end of the 21st century. The data is selected to match the downscaling realization, the source RCM and RP as closely as possible to attain comparability across different driving climate models. Further, methodology was developed as a combination of traditional and modern approaches. Stochastic modelling and data obtained by field measurements fall into the domain of the traditional methods, while the use of satellite data obtained from orbit and the application of GIS are considered as a more modern approach to the problem. Field data and their analysis will be the basis for predictions of groundwater behaviour, while modern technologies will be complementary methods in the estimates of the obtained projections. The

Crnojevića river has the most reliable series of spring discharge data and thus it was chosen for testing of established methodology.

Key words: climate changes, karst, climate projections, GRACE, GIS

SIMULATION OF MIGRATION OF NITRATE CONTAMINATION IN EPIKARST GROUNDWATER: A COLUMN LABORATORY METHOD

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The epikarst is a part of the karst outcrop that is located within the unsaturated zone of karst aquifer and represents a complex point of contact and mixing of unconsolidated material from the terrain surface, remains of carbonate rocks altered by corrosive water, flora and fauna, and their remains, which is partially saturated with groundwater. The study area for the applied multidisciplinary research was the karst massif of Suva Planina Mountain (Serbia), that is the part of the Carpathian-Balkan Mountain range. Among many other conducted research, the Na-fluorescein dye tracing test at Peč cave determined the velocity of the epikarst (subsurface) flow, while the experiment with contaminant, at the same location, defined the velocity of the contaminant migration. The data collected in the field, during the dye tracing experiment and experiment with "light" contaminant, were used for the design and development of a physical model of epikarst for experiments in laboratory conditions. During the experiment in the model of epikarst in laboratory conditions a contaminant of chemical origin: Ammonium nitrate, artificial nitrogen-based fertilizer was used. The concentration of nitrate in the contaminant (water solution) was 1160 mg/l and the specific electrical conductivity was 3070 μS/cm. During the experiment, nitrate concentration and specific electrical conductivity values were monitored every two hours until the epikarst model was completely discharged. The diagram of specific electrical conductivity showed that models of different epikarst composition react differently to the contaminant. However, in both models, the specific conductivity had an increased value in the first sample taken after the contaminant was introduced in the model. Mixing of two solutions (contaminated water and water in the model) resulted in quickly established balance. In terms of nitrate concentration in models, increased concentration has been recorded as well. Theoretically, the equilibrium concentration of nitrate in the models, in which the contaminant and "pure" water are mixed, is achieved, while small discrepancies originate from the present adsorption of nitrate on limestone rocks, but also from the mobilization of nitrate from soil particles. Experiments in the synthetic model of epikarst

have shown that it is possible to simulate the groundwater seepage through epikarst in conditions as natural one at the Peč cave site.

Key words: epikarst, model, nitrate, electrical conductivity

MAIN FEATURES OF THE INTEGRATED WATER MANAGEMENT OD KARST POLJES IN EASTERN HERCEGOVINA, CASE STUDY: LJUBINSKO POLJE IN THE TREBIŠNJICA RIVER BASIN

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Karst poljes in Eastern Herzegovina are subject to intense and prolonged flooding in winter and spring, and long-term droughts in summer. Ljubinjsko polje with the Bukov Potok, which is a flash flood prone stream of the the Trebisnjica basin, has typical hydrological features of karst poljes. Town of Ljubinje is situated in the lower part of the polje, while Konac ponor is at the lowest elevation (408m a.s.l). The ponor is surrounded by 800ha of agricultural land of extremely high quality. Agricultural production in Ljubinjsko polje is recognised as a possible contributor to the development of this area, provided that the existing water management limitations are removed. Although its surface area is 8.5km^2 and arable land is 7.7km^2, water deficits during growing season and flooding of the lowest parts of the polje at the beginning of the growing season significantly affect the development of intensive agricultural production.

Given the characteristics of this karst area, the flash flood prone character of the Bukov Potok, and unfavourable hydrological regimes in Ljubinjsko polje, it is paramount to define hydrogeological relations as precisely as possible (springs, area of watertight dam site and reservoir, underground connections, flood duration). In addition to these data, it is important to analyse erosion and corrosion characteristics, irrigation water needs, and water balance of the required storage volumes of potential reservoirs.

This paper presents the results of simulations of the existing situation in periods of flood flows using complex hydrological and hydraulic mathematical models, taking into account the characteristics of karst area. The main features of integrated water management are presented and the effects of these systems are verified. The aim is flow regime control, erosion control and irrigation for intensive agricultural production, and also the use of active flood protection in planned reservoirs, which will have multipurpose character. Only after the

implementation of the proposed integrated water management solutions in Ljubinjsko polje will it be possible to harmonise flow regimes and area development, i.e. primary economic activity (intensifying agricultural production using irrigation).

Key words: karst area, mathematical models, integrated water management, multipurpose reservoirs, irrigation development

HYDROGEOCHEMISTRY OF KARST SPRINGS OF ZAGROS AND SANANDAJ-SIRJAN ZONES IN NAHAVAND AREA (WESTERN IRAN) EMPHASES ON HEAVY METAL AND STABLE ISOTOPES

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Freshwater resources in alluvial aquifer are not sufficient for growing population, water resources in Karsts due to the high quality of water resources allocated for drinking water. The aim of study is Hydro geochemistry of karst springs of Zagros and Sanandaj-Sirjan zones in Gamasiyab basin (Western Iran) emphases on heavy metal and stable isotopes. Karstic springs of Kiyan, Gamasiab, Kengavarkohne, Faresban, Malusan and baruodab have multiplier discharge than other springs consumed for agriculture mainly and drinking water too. The research methodology is a field-analytical and laboratory-library that used by Arc GIS, SPSS, Excelc and Chemistry. Physicochemical and measured elements are: fluoride, nitrit, nitrate, sulfate, chlorine, sodium, calcium, water turbidity some of heavy metals and isotopic analysis. The focus of investigation in this study Gamasiab karstic spring because it is one of a biggest karstic spring of Zagros Mountains and origin of Karkhe River. One of the hypotheses is that the concentration of elements in karst Springs of Sanandaj-Sirjanis higher than Zagros Karst. For determining of hydro geochemical processes, integrated the results of this research, hydro geochemical studies, geological studies and available information. The expected results from this project shall enhance the general understanding of this karst water resources that will be useful for the long-term management of the resources as a potable water supply (information on the aquifer vulnerability, possible presence of geogenic contaminants, springs temporal flow regime, etc.). To evaluate the origin of water-soluble chemicals, Gibbs prepared two graphs for the ratio of Na / (Na + Ca) and Cl / (Cl + HCO3) to TDS. In samples with high Na / (Na + Ca) and Cl / (Cl + HCO3) ratios with TDS less than 100 mg/L, precipitation has the greatest effect on water chemistry. Combined diagram of Mg/ (Ca + Mg) versus SO4 (HCO3 + SO4) Samples of six springs show the role of dissolution of dolomite in the chemical composition of water. This

indicates that the carbonate rocks of this study area are of dolomite type. According to these diagrams, the main factor controlling water composition in springs is the weathering process of carbonated rocks. The concentration of karst springs in Sanandaj-Sirjan region is higher than Zagros and Zagros springs are less developed in terms of hydro geochemical evolution. Considering that there are metamorphic rocks in Sanandaj-Sirjan area that are in contact with limestone's and due to mineralization, they introduce metal compounds and minor (rare) elements in karst aquifers of this zone; At the same time, there are sedimentary formations in the Zagros region and there is no metamorphic formation, so the origin of rare ions in the Sanandaj-Sirjan region is related to metamorphic rocks.

Keywords: hydrogeochemistry, stable isotopes, karst springs, Zagros and Sanandaj-Sirjan zones, Gamasiyab basin, Iran

SIGNIFICANCE OF TURBULENT FLOW REGIME IN DISCRETE-CONTINUUM FLOW AND TRANSPORT MODELS OF KARST SYSTEMS

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Karst distributed numerical modelling has developed rapidly within the last few decades, mainly aiming at analysing the behaviour of karst systems. Due to the inherent duality of groundwater flow in karst systems, these models were presumed to have accountability for both laminar and turbulent flow regimes. However, the significance of flow regimes in the models has not been thoroughly investigated.

In this study, global sensitivity analysis via Method of Morris (MM) for groundwater flow (Q), solute transport (C), and heat transport (T) for a discrete-continuum model representing the downgradient parts of Freiheit karst system, Minnesota, U.S.A., was performed. Through MM, we aimed at determining the significances (i.e., total order sensitivity (μ^*)) of system parameters under the assumption of laminar (LCFR) and turbulent conduit flow regimes (TCFR).

The models revealed the extent of the effect of incorporating turbulent flow regimes in a small-scale karst model. Results showed that based on relatively high μ^* for Q, C, and T the models were generally highly sensitive to the roughness of conduit, which is the basis of turbulent flow. Based on the comparison of μ^* values among system parameters, the significances of most moderately sensitive parameters such as rates of recharge fraction to conduits and conduit associated drainage storages and horizontal matrix conductivities differed for the two flow regimes. Nevertheless, the conduit diameters and tortuosities had the highest μ^* in Q-C-T simulations, indicating the strong sensitivity of the models towards conduit parameters. This did not apply, however, to Q simulations under LCFR, where the recharge parameters became the most important factor. On the other hand, the exchange coefficients had the lowest μ^* for all Q-C-T simulations under both flow regimes, implying that the

conduit-matrix interaction was generally the least important factor in the models. Only certain input parameters such as concentrated recharge fractions and other least important parameters exhibited a monotonic relationship with the model outputs for Q-C-T under both flow regimes. The significance of other relevant parameters, accounting for interacting effects, also varied dynamically depending on the model parameterization. Overall, we highlighted the importance of conduits in discrete-continuum modelling of different processes in the studied karst system under either LCFR or TCFR.

Key words: karst system models, turbulent flow, Method of Morris, global sensitivity analysis, Freiheit karst system

EVALUATION OF TRANSFER FUNCTION NOISE MODELLING AND DIMENSIONALITY REDUCTION TECHNIQUES FOR KARST SYSTEMS

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Though karst aquifers are important sources of drinking water on a global scale, these systems are still insufficiently understood regarding adequate model representation. Time Series Analysis (TSA), as a data-driven approach, has been demonstrated to be useful for the characterization of karst system hydrodynamics with sparse data. Recently, transfer function noise (TFN) modelling with predefined impulse response functions, as a linear TSA-method, has been applied to analyze and manage groundwater systems. In this approach, impulse response functions in continuous time are used to describe the system response (e.g., spring discharge) to independent stress input time series (e.g., precipitation).

Depending on the TFN model complexity and the kind of response functions used, the model could have a large number of parameters, potentially causing ambiguity of the calibration. This is further aggravated if the physical meaning of model parameters is unclear such that parameter values cannot be constrained or verified by field measurements.

Dimensionality reduction (DR) techniques can be used to study the model parameter space, identify most important parameters, and potentially lower the total number of model dimensions. Previous applications in karst hydrology employ the linear DR method of active subspaces. A broad variety of linear and non-linear DR techniques exist in statistics and computer science, which were not yet adopted for karst or other water resources,

The goal of this study is to evaluate the suitability of TFN models and DR techniques to simulate karst systems. To reach this objective, the following steps are carried out. First, we develop synthetic karst systems using the distributed numerical flow code MODFLOW-CFP. With these models we generate data to be in turn modelled by the TFN approach. After fitting the TFN models to the synthetic data, the corresponding parameter spaces are explored and studied using DR methods. In combination with statistical model diagnostics, all results are used to evaluate the applicability of TFN models for karst systems. Lastly, we study a real karst system with the proposed framework.

Preliminary results show that the TFN approach may be used to model karst spring discharge, as evaluated according to fit metrics. When using complex TFN models, though, the initial solutions were found not to be unique. Lower dimensional structures could be identified independently of general TFN model structure or defined response function. Preliminarily, linear DR may be insufficient in capturing the lower dimensional structures, however giving the most useful results for further applications.

Key words: transfer function noise modelling, time series analysis, dimensionality reduction, surrogate model, discrete continuum model

LINEARIZATION OF INPUT SIGNAL AS A NECESSARY TOOL IN STOCHASTIC MODELING OF KARST GROUNDWATER

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Modelling of karst hydrogeological systems is a very complicated task, bearing in mind that for a deterministic model one should know the internal physical processes of precipitation transformation into discharge, while for a stochastic model nonlinear dynamic systems such as karst should be simulated by linear regression equations. Stochastic models need linearization of input time series due to often large residual in the recession period. This occur because the model is not able to absorb single rain episodes, which are plotted as white noise of the model. Also, zero values and consideration of gross rather than effective precipitation have a great influence on the transformation of precipitation into discharge. On the other hand, a karst hydrogeological system has the possibility of internal amortization of individual rains and zero values, which is very difficult to describe by stochastic mathematical methods. These are the main reasons why karst is considered a black box model. Thus, transfer functions are used in practice to amortize or remove trends or cycles from specific time series. Transfer functions can be approximated by mathematical functions - arithmetic mean, polynomial function, or some more complex mathematical function. One of the most applicable transfer functions for processing time series is the moving average filter, which finds average values from several previous and next values of the time series for a certain time step (moving average window). This linear filter can successfully eliminate days without rain, which greatly reduce the coefficient of multiple regression in the model. Also, a moving average makes it possible to attenuate the input signal into the system, giving a more reliable simulation model. The moving average window depends on the frequency of observation of the time series and the observed trends that want to be removed. Since the time series of precipitation are usually observed daily, the moving average window can be expressed in days. Determining the moving average window will also depend on the number of days without rain, which should be completely removed from the time series. The example of the Seljašnica karst spring, for which a stochastic model with filtered and unfiltered precipitation was made, clearly indicates the necessity of linearization of the

input signal, since the residues in the recession period are much smaller if transformed precipitation is used in the model.

Key words: karst groundwater, stochastic modelling, transfer function, moving average

APPLICATION OF MODFLOW-CFP TO EVALUATE DUAL FLOW SCENARIOS IN THE SUB-SURFACE OF THE YUCATAN KARST

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Karst aquifers are complex systems with high a heterogeneity and anisotropy. The duality of karst is expressed by several processes such as recharge, infiltration, storage and flow. Regarding the later, flow conditions are dissimilar between the rock matrix and the conduit system; the former being assumed as laminar, the later as turbulent. Given that numerical models based on Darcy's law are limited to simulate turbulent conditions in complex solutional conduits, an approach to simulate the effect of conduits, or preferential flow layers, is necessary for karst.

The Conduit Flow Process (CFP), developed by the U.S. Geological Survey (USGS), helps to simulate this duality in flow commonly found in karst aquifers. In this work, the CFP was applied in the Yucatan karst, categorized as a well-developed karst system with systems of conduits of considerable diameter. Unfortunately, there is a lack of data regarding the subsurface in terms of the conduits' three-dimensional location and connectivity. For this reason, the CFP was applied evaluating different flow scenarios (preferential flow layers/conduits) in order to investigate possible flow conditions in the subsurface of Yucatan.

The Merida Metropolitan Area (MMA), a densely populated region in the Mexican state of Yucatan, was selected as the area of interest for this study. Piezometric data from 48 monitoring wells, for the period 1996-2004, were utilized as the basis to calibrate the model; two measurements per year (representing dry and wet seasons) were utilized for the temporal discretization of the model. Similarly, measured precipitation from 8 climatic stations was included as stressor of the system for the same period. Results were compared with those from a previous groundwater flow model that have been applied in the same area utilizing an equivalent porous media (EPM) approach. With the application of the CFP, it was possible to evaluate laminar-

turbulent flow configurations in order to provide more realistic insights regarding groundwater flow in this karst region. Results provide important considerations for further studies regarding recharge-discharge processes in Yucatan.

Key words: karst, Yucatan, CFP

NUMERICAL MODELING ABRASIONAL WEAR OF SCALLOPED BEDROCK IN CAVES

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The extent to which chemical and mechanical erosion each contribute to the erosion of cave passages in limestone is an open question. In mixed cave riverbeds that are partially alluviated and partially exposed limestone bedrock, we sometimes see clearly scalloped bedrock. The uniquely soluble properties of limestone imply that these scallops that tessellate to comprise the scalloped bedrock are the result of chemical dissolution. However, because we see silt, sand, and gravel, and because when we visit the same reach of the cave river many times, we see those sediment deposits shift in size and location, we infer that there may also be mechanical abrasion from sediment impacts on the scalloped bedrock surface. We compared the equations that describe dissolution of limestone with those that describe abrasion of bedrock to prove that dissolution and abrasion may be co-occurring processes. Using our numerical model, DKARST (Does karst abrasion result in scalloped tunnels?), in conjunction with previous data from dissolution studies, we quantified parameters that delineate three distinct erosional zones according to the likelihood of contribution to overall erosion from dissolution, abrasion, or both processes combined. We then generalized those erosional zones to a range of scalloped bedrock morphology characteristics wavelengths. Our investigation of the role of mechanical erosion to the scalloping of bedrock in caves provides insight into the settling velocities of particles in turbulent flow over rough beds, as well as the relative roles played by mechanical and chemical processes in broader scale landscape evolution, particularly in karst regions dominated by carbonate bedrock.

Key words: scalloped bedrock surface, DKARST

CONCEPTUAL HYDROGEOLOGICAL MODEL OF DEEP KARST AQUIFER IN SOUTH MORAVIA – LOWER AUSTRIA REGION

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A region of South Moravia in the Czech Republic and Lower Austria is well-known for the use of thermal mineral water extracted from a Jurassic carbonate aquifer. A conceptual model was developed to discover the groundwater flow pattern and natural recharge essential to assess the potential of the karst aquifer for the water exploitation. The Jurassic aquifer is buried below the Neogene foredeep, underlain by a crystalline basement of Bohemian Massif, and continues to the southeast below the Western Carpathians. Jurassic sediments, mainly composed of carbonates, increase the thickness in this direction due to the decline of the crystalline basement. The top of Jurassic carbonates occurs in the study region at depth from 100 to 3000 m below sea level. The conceptual model covers both the major Jurassic carbonates and hydraulically connected underlying and overlying rocks. Because of the considerable depth of this hydrogeological structure, the conceptual model is based mainly on archive data obtained from deep wells located in the study region. To identify the groundwater flow directions, the hydraulic heads were derived from pressure observations. To get correct values of hydraulic heads, the groundwater density was calculated reflecting various mineralization and temperature. Derived general groundwater flow directions are from northwest and southeast into the drainage zone identified in the central part, which is parallel to the course of the Dyje river. The conceptual model was complemented by a spatial distribution of hydraulic parameters. These parameters were derived from hydrodynamic and laboratory tests. The hydraulic conductivity value of the carbonates is spread over a very wide range from 10^{-4} to 10^{-9} m.s^{-1}. High values of hydraulic conductivity near the drainage zone indicate the presence of a well-developed drainage network. The distribution of hydraulic conductivity values in the vertical direction does not indicates the presence of an epikarst zone. Reflecting the relatively low groundwater mineralization in the north-western part of the aquifer, more intensive recharge occurs there through the weathered crystalline basement. A less intense inflow of high mineralized water comes from the southeast, where most of the groundwater is fossil. Identified natural

recharge and groundwater flow pattern indicate considerable potential for mineral water exploitation.

The study was carried out within the project Hydrothermal potential of the area HTPO (ATCZ167).

Key words: deep karst aquifer, conceptual model, Jurassic carbonates, mineral water, groundwater recharge

STOCHASTIC PREDICTION OF TEMPORAL VARIATIONS OF KARST GROUNDWATER REGIME IN FUNCTION OF SUSTAINABLE MANAGEMENT: CASE STUDY MOKRA KARST SPRING (SE SERBIA)

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Quantitative and qualitative monitoring of karst groundwater has a very important role in defining the strategy of groundwater resource exploitation in a rational and sustainable way. Properly determined frequency of qualitative groundwater monitoring can provide insight into fluctuations in groundwater quality parameters, which can be useful especially if the monitored karst spring is tapped for water supply purposes. Stochastic analysis of karst groundwater quality parameters is an important element of the concept of groundwater resources management, which can provide important data on the functioning of the system, as well as the correlation of input and output data. The success of stochastic analyzes of qualitative parameters will depend on data availability, as well as on their accuracy. Quality parameters that are usually analyzed are those assumed to be directly dependent on the recharge rate and groundwater discharge: turbidity, electrical conductivity, water temperature, etc. In addition to chemical parameters, stochastic analysis can also include the contents of some microcomponents, i.e. bacteria. Stochastic analysis and simulation of qualitative parameters was carried out for time series of precipitation and turbidity in the period October 2016 - September 2017 for the Mokra karst spring which has been tapped for water supply of Niš. Analyzes showed a delay of increased turbidity of 5 days at the Mokra spring, while the discharge reacts on precipitation after 7 days. In other words, turbidity firstly reacts on rainy episodes at the Mokra karst spring, while discharge reacts secondly, and later also increases the values of turbidity by induced suspended material. The enormous increase in turbidity that occurred in 2020 at the Mokra spring during which the entire groundwater source had to be closed, clearly indicates the need to form a model that would announce the arrival of extreme values of qualitative parameters a few days in advance. One of the types of adequate qualitative groundwater monitoring which can be set up to sustainably use karst groundwater is the installation of an early warning system (EWS) that can help water companies to quickly respond to any changes in the input signals of karst systems. EWS has a role in the instantaneous observation of the karst

system reaction to changes in the chemical characteristics of the input signal. With EWS, it is possible to monitor karst events caused by rainy episodes using satellite networked groundwater measurement and sampling stations in combination with analyzes of microbiological fecal pollution indicators in the laboratory.
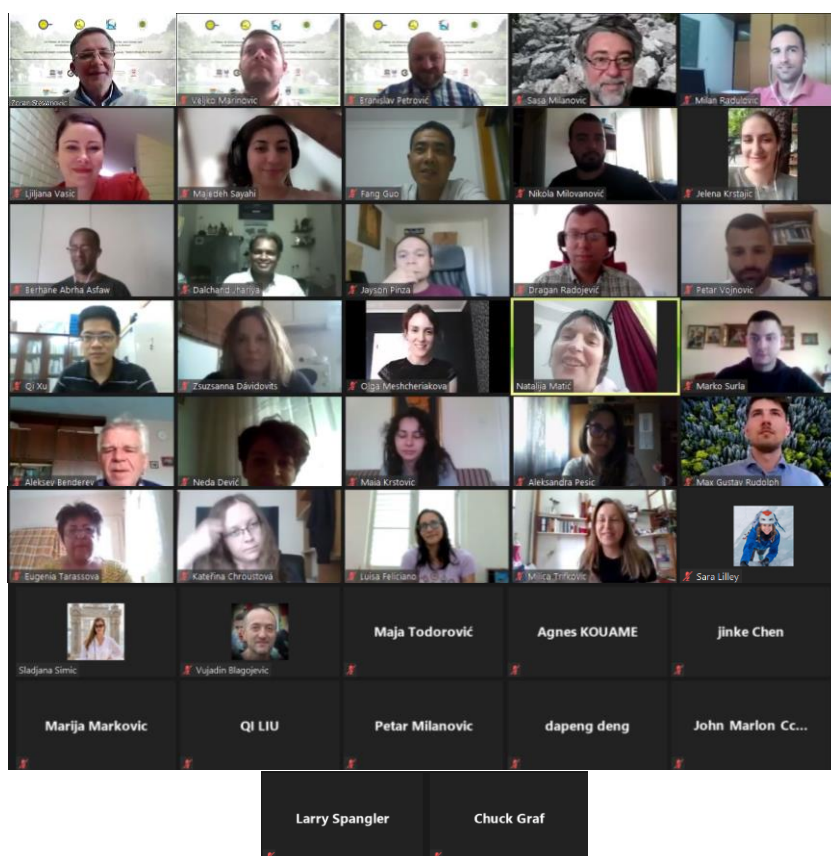
Key words: karst groundwater, stochastic model, water quality, early warning system

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