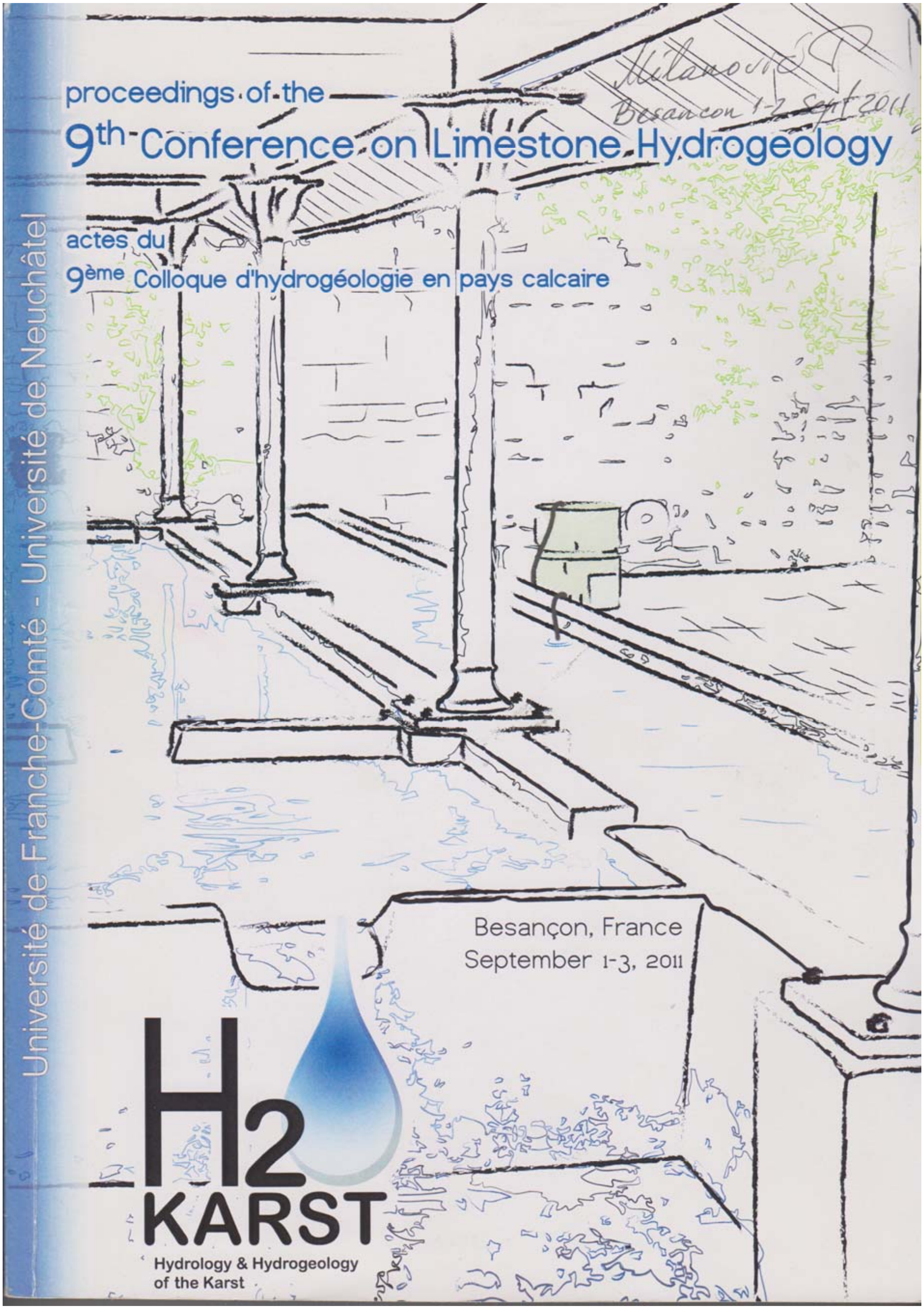

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Monitoring and Modeling of Karst System as a Base for its Evaluation and Utilization – a Case Study from Eeastern Serbia

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Abstract

The study area is Beljanica Mountain, a part of the Carpathian Balkan arch (northern Alpine branch) in eastern Serbia, which covers an area of about 300 km^2 and consists mostly of Jurassic and Cretaceous limestone. Numerous surface karst features, long caves and several large karstic springs located in Beljanica's piedmont along the contact of karstic and non-karstic rocks are all indicators of an intense karstification. Currently, the large karstic water reserves of Beljanica Mountain are not properly utilized because of their distance from main consumers, and also because of objection of national water managers that spring has not a stable discharge particularly during recession periods. Due to its unpolluted and high quality water, the area has a good prospect for future water supply, and provides an opportunity for artificial regulation and for the design and implementation of specific tapping structures.

This paper includes an analysis of the discharge regime of major springs based on historical and newly collected data, the correlation of spring discharges with physico-chemical characteristics of the spring waters, and the main findings of the created 3D ArcGIS model of karst interior. The results of karst aquifer monitoring (both quantitative and qualitative) are linked with the results of extensive field geological and speleological survey of the upper non-saturated part of the karst (such as sinkholes, pits and the caves) as well as the investigation of the permanently saturated deeper part of the aquifer (including the diving methods). The model is based on data from the existing 69 caves, 15 sinks and 1682 classified dolines (sinkholes). The total length of the karst channels network, calculated using the GIS model and presented in a 3D environment, is 647 km. The catchment areas of five major springs that drain the areas are estimated to range from only 7 to 124 km^2 (Vrelo Mlave Spring). The groundwater exploitable reserves of Beljanica karst aquifer are estimated to be over 4 m^3/s. The waters are low mineralized, unpolluted and have great potential for water supply.

Key words: karst, monitoring, model, discharge, Beljanica, Serbia

1. Introduction

Beljanica Mountain in the Carpathian karst of eastern Serbia was chosen to be a test area for detailed field survey, for the creation of a complex physical model in GIS, and for the establishment of a pilot monitoring system for a study of the possible impact of climate change on karstic aquifer and the discharge of springs (SEE Project CCWaterS).

Analysis of various parameters obtained by quantitative and qualitative monitoring of groundwater characteristics and their analysis through the established physical model provide data on the relationship between the water recharge and discharge zone on the Beljanica karstic massif. Analyzing the geometry of the main karst conduits in the saturated zone and the connection with conduits in the aeration zone as well as in the zone of groundwater level fluctuation, an insight into karst channels has been provided and enabled the creation of the 3-D model of karst channels. Such a model can be used for an analysis of speleogenesis and hydrogeological characteristics of the area.

2. Some main characteristics of Beljanica karst aquifer

Position – The Beljanica karst massif is located in the eastern part of Serbia. The Beljanica mountain range is an anticline (Kucaj-Beljanica structure) composed of Jurassic and Cretaceous carbonate rocks generally inclined from the central to peripheral parts of the massif. The highest point of Beljanica has an altitude of 1339 m asl, while its average elevation is between 800 and 900 m asl. The complex geomorphological structure and the presence of different surface and underground processes are the result of geology and an intense karstification (STEVANOVIC 1991).

Morphology - Karst of Beljanca Mountain is characterized by a large number of surface and underground morphological forms. Surface forms are well developed and widely distributed. The main forms of Beljanica karst are dolines, caves and pits, and their classification and exploration was of great importance in the process of karst aquifer modeling. A total of 1682 dolines was registered on the Beljanica massif, some of which have an area of more than 82000 m^2 (the smallest has an area of only 19 m^2). In the interior of the karst massif there are 69 registered caves, some with a depth of over 150 m; the length of the channels is more than 500 m (MILANOVIC S. 2010).

Hydrogeology - For the purpose of karst aquifer modeling, hydrogeological characteristics of karst aquifers were analyzed. Main attention was paid to, and discharge measurements and physical and chemical characteristics of the major drainage areas were delineated from, tracing tests conducted in the Beljanica massif (STEVANOVIC 1994).

The precipitation which is formed from rain and snow infiltrates to the epikarst of the Beljanica karst aquifer and through a number of swallow holes within the massif and in the riverbeds of Male Tisnica and Suvi Do sinking streams. Some major streams do not dry out even during low water periods, and they sink in a series of concentric holes (Rečka, Busovata, Krivulja, Beljanička Recka etc.) with a swallowing capacity from 10 to more than 500 l/s.

Beljanica karst aquifer drains through a large number of karst springs along the edges of the massif at the contact of karst and non-karst (Fig. 1). In the area of Beljanica 45 karst springs and sources are registered. The largest number of karstic springs is drained from the local epikarst zone with a relatively low capacity which rarely exceeds 0.5 l/s. In addition, a series of karstic springs along the edge of Beljanica Mountain has a significantly higher capacity. In some karstic springs the minimum discharge is over 300 l/s, while the maximum discharge is over 15 m^3/s as in case of Vrelo Mlave Spring (STEVANOVIC et al. 2010). In total, five major catchments have been defined, all drained by strong karst springs. The main hydrogeological characteristic of the northern part of the aquifer is its deep siphonal circulation, where cave divers explored channels of Krupaja Spring to a depth of 120 m and Mlava Spring, whose channels in fact go much deeper (studies have not been completed) to a depth of 73 m (MILANOVIC S. 2007).

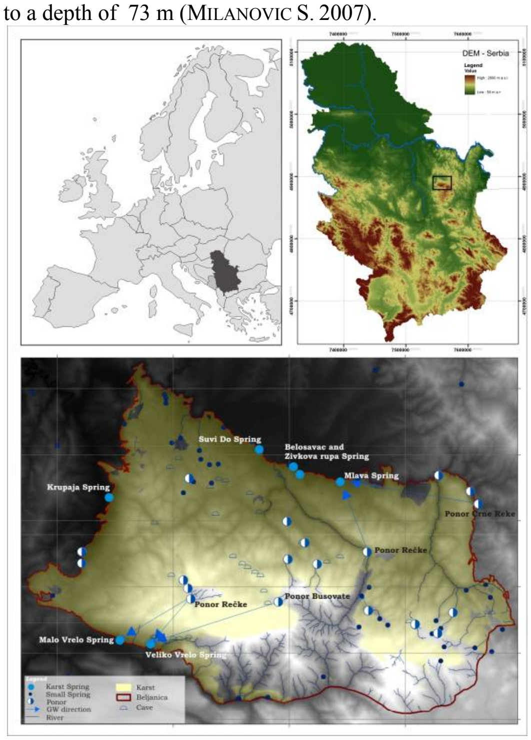

Fig. 1 Location map of Beljanica massif including position of hydrogeological features, monitoring network, and main directions of groundwater flow

3. Simultaneous monitoring of regime and physical-chemical characteristics of Beljanica aquifer

The data obtained by simultaneous monitoring of quantitative and qualitative characteristics of karstic springs that drain the Beljanica karstic aquifer significantly contributed to defining the separate hydrogeological catchment areas of five karstic springs.

Monitoring data of the regime for five springs that drain Beljanica aquifer, Vrelo Mlava Spring, Belosavac Spring, Krupajsko Spring, Malo Vrelo and Veliko Vrelo Spring, for the period (2009-2011) made possible the comparative analysis of regime, precipitation and water quality. Those analyses serve as one of the main input parameters for the formation of a conceptual hydrogeological model and as the parameters for calibration of a 3D physical model of karst conduits of this complex karst system.

The continuous monitoring (daily monitoring of regime and monthly physical and chemical characteristics), shows that the total yield of springs which drain the northern part of Beljanica in period 2009-2010 averages Q_{av}=6.11 m^3/s, while the average yield for the southern rim of Beljanica or for Malo and Veliko Vrelo Springs is Q_{av}=1.25 m^3/s. This leads to a total sum of mean yield of the Beljanica Mt. of $Q_{av.tot.}$=7.36 m^3/s. Comparative diagrams (Fig 2.) show that change in pH and temperature depends on the yield of springs: the springs from the monitoring network (Belosavac, Malo and Veliko Vrelo) with increasing yield decreases the pH, while in periods of recession the pH value increases up to 8.5. This increase in pH values in the extremely dry period indicates a considerable influence of recharge from the central part of Beljanica Mountain and from Paleozoic rocks that generate waters which downstream are directly infiltrated into karstified rocks (epikarst and open karst). With increasing precipitation and significant infiltration of water into aquifer, pH declines.

The ratio of water temperature and regime is equal for the whole aquifer system: with an increase in discharge the water temperature declines due to the shorter retention period. In the summer, the impact of climate elements is smaller and the temperature of the karst underground remains stable.

Generally, it can be concluded that simultaneous measurements of yield and physico-chemical characteristics of karstic springs can indicate a connection between recharge and discharge zones, and that their correlation with earlier conducted tracer tests STEVANOVIC (1994) as well as with a 3D model of karst conduits distribution may determine the hydrogeological watersheds, or redistribution of water within the karst aquifer.

4. 3D model of karst channels distribution on Beljanica aquifer

For the physical model of the karst underground the ArcGIS program was used along with some additional associated special software (MILANOVIC S. 2010). To set the model in a "real" spatial environment, some detailed spatial and surface layers were created as well as a time series of simultaneous measurements. Linked layers and an associated base form a basis for further analysis of karst aquifers through different model components.

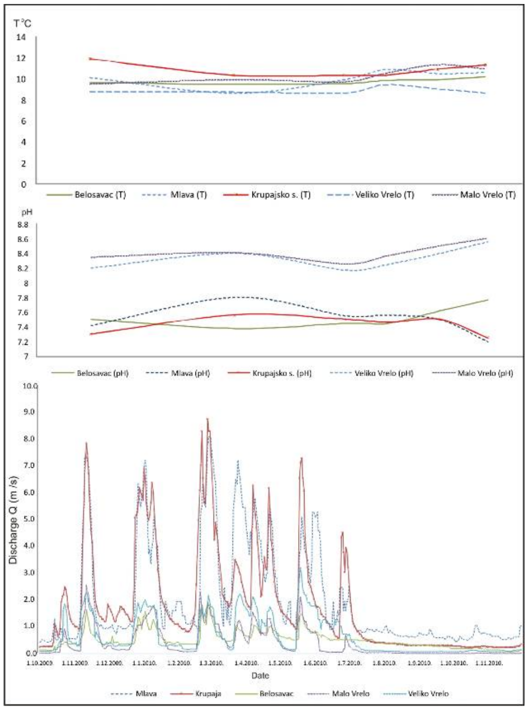

Fig. 2 Comparative diagrams Q/T and Q/pH for analyzed springs of Beljanica Mountain

By defining the main directions and orientation of karst conduits (followed by a small percentage error), layers of potential distribution of karst channels were created. The model based on deterministic laws included input parameters as the main channels of the first and second order connected with the other channels as a function of water transfer from the top surface into the deep ground and towards output parameters approximated with all zones and points of discharges. The conversion from 2-D known elements into 3-D model points and the determination of the Z coordinate (with the possible correction of X, Y coordinates) is done through a multi parameter morphological model. The input data of the model are represented by the 69 caves, 15 sinks and 1682 sinkholes explored. As output from the model, more than 6000 data points (registered in database) were calculated. There are 60 different data for each point (coordinates, groundwater table, type of channel, next point, connection with, orientation of channel, hydrogeological function etc.), which means that the model is determined by more than 360000 data (MILANOVIC S. 2010).

The total length of the karst channels network which is calculated using the GIS model and presented in a 3D environment is 647.29 km. The first category defined by ensured information concerning the reliability and size contains 84.81 km long conduit system. The second category of channels is proportionally smaller with less reliability and the model calculated a 106.90 km length of conduits. The first two aside, it is imagined that the third category of channels connects the recharge zone (area) with conduits of the deeper part of the karst aquifer. Their reliability is certainly good, but assurance of their sizes is considerably less so. The length of these channels is around 455.58 km. The complete network of karst channels is shown in Figure 3 (MILANOVIC S.2010).

5. Discussion

On the basis of the modeling and simultaneous field studies, it was noted that the circulation of the Beljanica aquifer groundwater depends on the hydrological situation and piezometric level and on the monitoring of quality characteristics diverted in different directions, and further that there is a redistribution of water within the aquifer, with no constant watersheds.

A real spatial-oriented network providing potential karst channels which help as input parameters for further modeling of the underground karst development and the status and distribution of underground conduits was achieved after correlating elements of the 3D model and the data from simultaneous observations.

Through such a complex model and its analysis, the hydrogeological watersheds can be estimated. Realistic watershed areas are those that represent the distribution of water according to the scenario for the periods of medium waters (neither extreme maximums nor minimums). In this case, the largest is the Vrelo Mlave catchment which comprises some 124 km^2. The Belosavac Spring watershed covers 27 km^2, while 85 km^2 belongs to the Krupajsko Spring (Fig. 4). Malo Vrelo Spring is the smallest catchment in Beljanica covering some 7 km^2, while Veliko Vrelo Spring comprises some 24 km^2.

According to monitoring data for period 2009-2010, the total discharge of the Beljanica springs are over 7 m^3/s. When these data are compared with average annual discharges for the period 1961-2000, the conclusion is that the mean annual flow during the period 2009-2010 is higher by almost 50% (MILANOVIC S. et al. 2010). This is, however, in compliance with higher rainfall rates for one of the wettest hydrological years in decades.

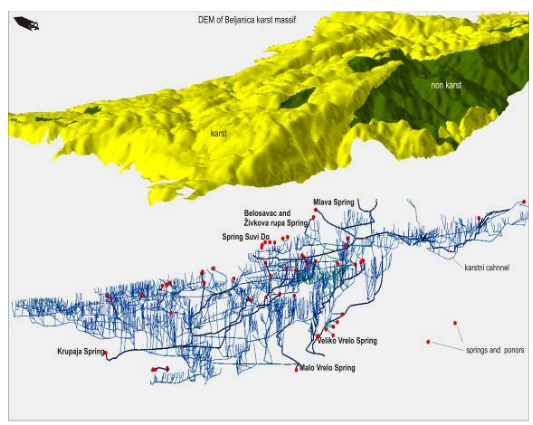

Fig. 3 3-D network of Beljanica aquifer karst channels

In terms of hydrogeological setting Beljanica Mt. is one of the best-explored karstic massifs in Serbia. It is a well-preserved and still undamaged nature reserve area with large groundwater reserves. The exploitable amount is equal to 3.4 m^3/s and 0.65 m^3/s in the northern and southern parts, respectively. This large amount of water that can be sustainably used is in fact equal to around 17% of the total amount of water which Serbia currently extracts for the population and industry. It is very important to ensure the preventive protection of karst groundwater for future generations but also to study the possible impact of climate changes on this important reservoir of clean waters.

Fig. 4 Krupajsko Spring on Beljanica mountain

6. Conclusion

The model of karst aquifer obtained through a comparative analysis of the 3D model of karst channels and the data of simultaneous measurements of the basic quantitative and qualitative characteristics of groundwater clearly indicates specific hydrogeological conditions. Beljanica aquifer is a very complex hydrogeological system, with the consequence that the different levels of groundwater and saturated channels often have a different redistribution of water in the interior sub-watersheds (Fig. 5), as well as a change in the qualitative characteristics of water (which is particularly reflected in the pH value, temperature, oxygen concentration, electrical conductivity and hydrocarbonates).

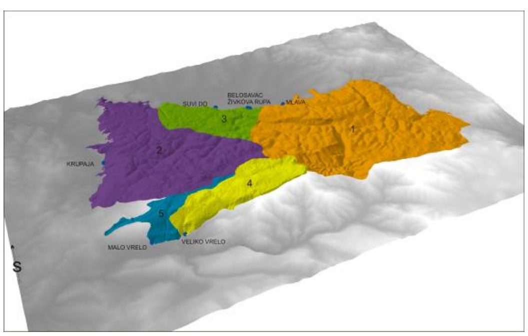

Fig. 5 Sub-watersheds of Beljanica aquifer: 1- Mlava spring watershed, 2- Krupaja spring watershed, 3- Belosavac & Živkova rupa springs watershed, 4- Veliko Vrelo spring watershed and 5- Malo Vrelo spring watershed

Finally, we should emphasize that the complex field research and its results from the continuous monitoring and the correlation of those results with the 3D model of karst conduit enables the reconstruction and modeling of complex karst aquifer, including its spatial, temporal, quantitative and qualitative characteristics. The results obtained favour the wide application of such an approach as a base for sustainable water management and appropriate utilization of aquifers with large groundwater reserves.

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