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QUANTITATIVE ANALYSIS OF KARST SPRING REGIME - CASE EXAMPLE OF BLEDERIJA SUBTHERMAL KARST SPRING IN EASTERN SERBIA

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Abstract: Karst aquifers are characterized as a highly heterogeneous media which affects the behaviour of the outflow regime. On the example of Blederija subthermal karst spring, located on the southeastern part of Miroč mts, complex quantitative analysis was carried out, in order to obtain new insights into the hydraulic mechanism of the discharge regime. Outflow regime is characterized by frequent mixing of a "normal" and increased temperature waters. Binary karst hydrogeological system and the location of ponor zones caused the specific variation of the catchment area, which is certainly reflected in the runoff regime. Time series analysis of climatic parameters, discharge rate and water temperature was applied in order to separate interconnected flow system e.g. base and fast (direct) flow components. Obtained results indicate a complex hydraulic mechanism of karst aquifer, caused by transferring pulse pressure through the karst hydrogeological system.

Key Words: Subthermal karst spring, regime analysis, time series, karst hydrogeological system, Miroč mts

INTRODUCTION

Karst springs hydrograms are very often used for the characterization of the karst aquifer. Discharge analysis and correlation with the changes of climate parameters can be used to understand the functioning of the karst system (Jemcov & Petric, 2010). This is particularly important for gravitational springs where discharge often changes a hundred times over and the influence of the climate is pronounced. On the other hand, deep siphonal springs possess much smaller discharge and temperature variations. But, there are some karst subthermal springs with significant changes in capacity and temperature; which is usually the result of mixing with colder karst groundwaters. In such circumstances, time series regime analysis can help us to understand the discharge mechanism as well as the recharge conditions. This methodology is applied for better understanding of Blederija subthermal karst aquifer.

Blederija is a karst spring which drains the Miroč karst massif in eastern Serbia. Karst aquifer is formed in fractured and highly-karstified massive Upper Jurassic limestones (Stevanovic et al. 1996). A significant portion of the spring catchment area is made up of low permeable Cretaceous clastic rocks, enabling the formation of network of surface streams, which sinks as they pass through the karstic parts (Fig. 1). At times of high-water flows, most of the surface streams sink via the ponor Cvetanovac. At the discharge zone, cold spring and subthermal spring (called mixed spring in this paper due to the results of regime monitoring) are located at the distance smaller than 10 m. The average discharge of the Blederija springs is 280 l/s (Prohaska et al., 2001).

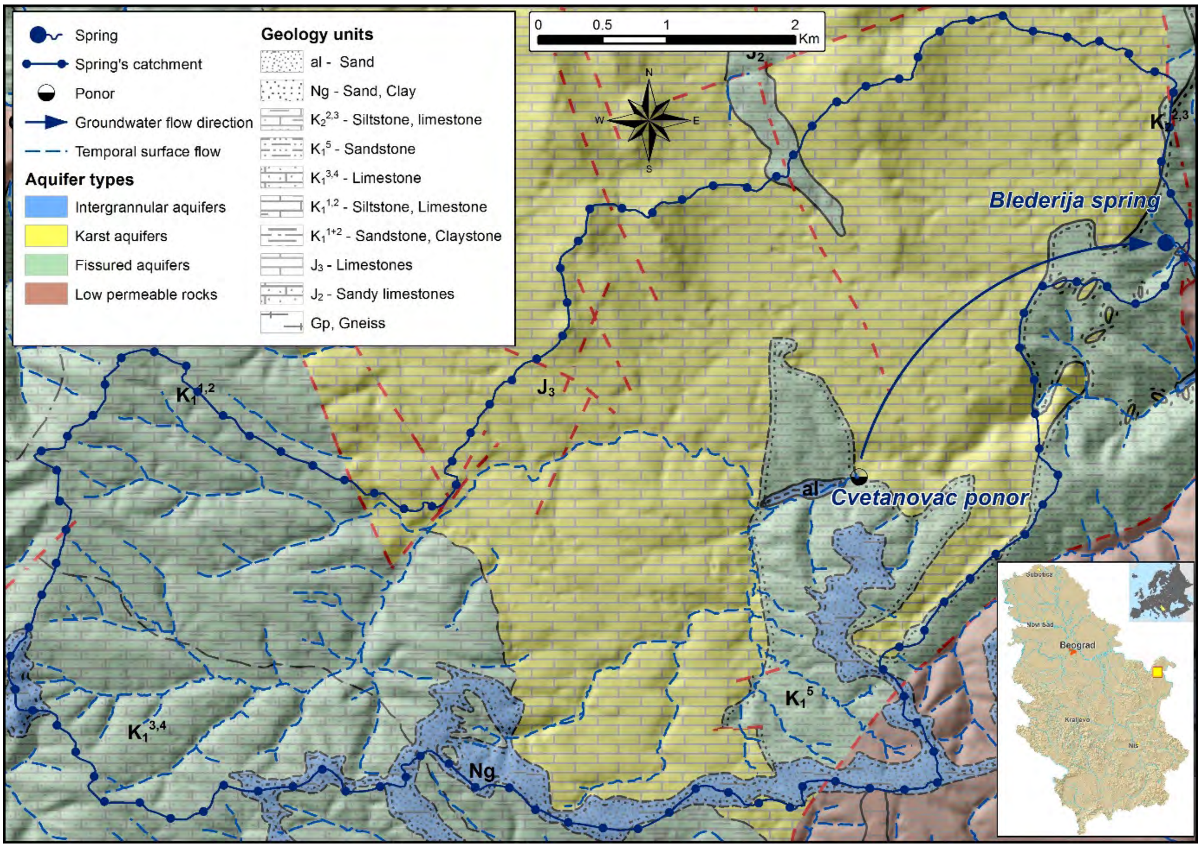

Fig. 1 Hydrogeology map of the Blederija Spring’s catchment area.

DATA AND METHODS

In order to understand the recharge and discharge mechanism of Blederija spring, long term monitoring measurement were conducted. Regime survey included: temperature measurement at three locations (Blederija mixed spring, Blederija cold spring and Blederija stream 10 m after the confluence of mixed and cold spring), surface water level and flow measurements of Blederija stream, climate measurements. All measurements were done during the period 17.03.2011-10.04.2014, which covers a three year period.

The water temperature was measured every 5 days with digital and mercury thermometer. In order to assess the capacity of Blederija stream water level gauge was installed and measurement was conducted with 5 day interval also. In the period of high waters measurements were done each day. Flow measurements were also conducted several times. In the vicinity of the spring, a meteorological station with participation, air temperature and wind speed and direction measurement was also installed. Precipitation data was also collected from the Miroč rainfall station located near the upper parts of the spring’s catchment. Along with this, data about the daily climate changes was collected from the Negotin and Crni Vrh meteorological stations where digital climate measurement is being done for a long period.

Beside the regime monitoring, field explorations were made along with dye test. Temperature and flow data were used for hydrograph separation. Time series analysis was used to understand hydraulic behavior of the Blederija karst system. All of obtained results enabled the establishment of the conceptual model.

MAIN RESULTS AND DISCUSSION

The first step in applied time series analysis was hydrograph separation according to the water temperature, because direct measuring of the springs discharge was impossible to conduct due to the narrow zone of springs outflow. Spring discharges were calculated according to the heat and mass continuum equations (Kobayashi, 1985):

$$Q_{sum} = Q_{cold} + Q_{mix} \ (or \ m_{sum}=m_{cold} + m_{mix}) \qquad (1)$$

$$m_{sum} \cdot c \cdot T_{sum}=m_{cold} \cdot c \cdot T_{cold} + m_{mix} \cdot c \cdot T_{mix} \qquad (2)$$

where Q_{sum} is the Blederija stream flow, Q_{cold} is the Blederija cold spring discharge, Q_{mix} is the Blederija mixed spring discharge, m is water mass, c is specific heat and T is water temperature.

Combining the upper two equations, hydrograph separation was obtained (Fig. 2) based on the following relation:

$$Q_{mix}=Q_{sum} \cdot (T_{sum}-T_{cold})/(T_{mix}-T_{cold}) \qquad (3)$$

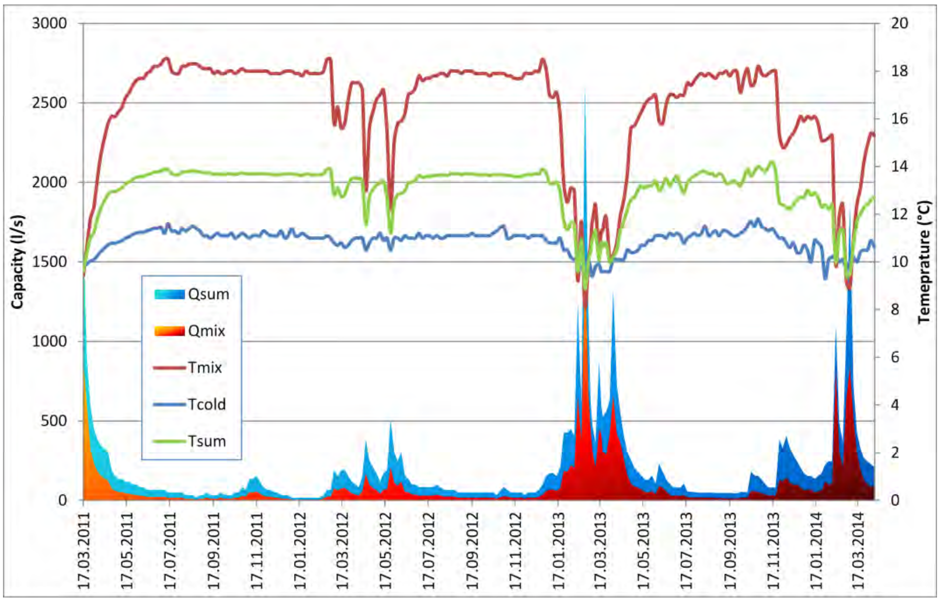

Fig. 2 Hydrograph separation based on thermal equilibrium

Temperature measurements have showed some unexpected results. The temperature of the Blederija mixed spring in dry period reached the values of 18.5 ºC. In the periods of snow melting, the mixed spring capacity significantly increases and temperature decreases for almost 10 degrees. In the previous studies, these phenomena were explained as resulting from a simple mixture with the groundwater from Blederija cold spring. However, in the highest water periods, temperature of the mixed spring is falling below the temperature of Blederija cold spring (T_{mix}=8.1ºC, T_{cold}=9.7ºC). These facts suggest to the possibilities that the main cause of lowering water temperature of Blederija mixed spring might not be the mixture with the water from the cold spring. Temperature decrease could be due to mixture with groundwater coming from the eastern parts of the catchment, where large portion of surface water recharges the karst aquifer via the Cvetanovac ponor. A dye test conducted in December 2013 has confirmed previous assumption. Tracer (1 kg of uranin) was injected in ponor Cvetanovac. Tracer was detected 2.5 days later only at the Blederija mixed spring, but not in the cold spring.

Fig. 3 Dye test – verified connection of the Cvetanovac ponor and Blederija mixed spring

In order to properly analyze recharge-discharge relation, input component – precipitation was converted to effective precipitation. With purpose to separate various processes in air, vegetation and soil from the processes within the karst aquifer system, the interception on vegetation cover, snow and snowmelt were assessed to define effective precipitation, or the quantity of precipitation that reached the ground (Jemcov & Petric, 2009).

One of the possible methods to study karst aquifer behavior is the time series analysis of the recharge and discharge data as functions of the karst hydrogeological system (Jemcov & Petric, 2010). Obtained analysis presents complementary methods along with other field methods of karst groundwater exploration (eg. dye test) in order to obtain new insights into the hydraulic mechanism of the discharge regime.

The univariate analysis characterizes the individual structure of time. The autocorrelograms of all of three functions (Fig 4.) exceeds the confidence limits for approximately 13-15 lag (~ 65-75 days), which implies that system is well structured, and storage is significant.

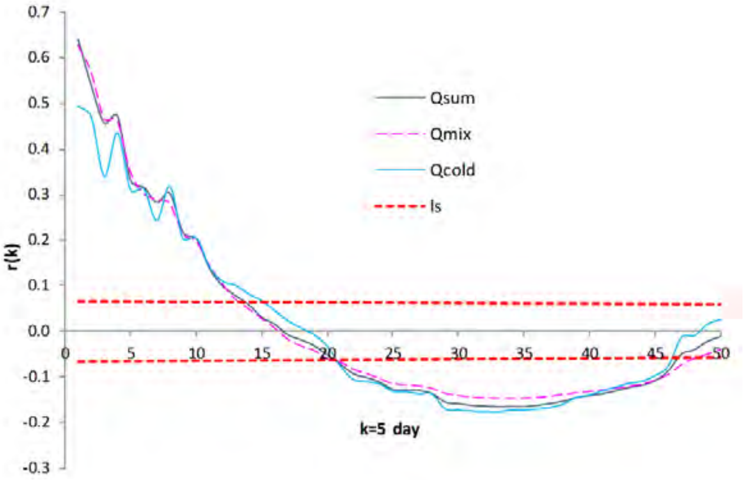

Fig. 4 Autocorrelation function of discharge components of the Blederija source
Legend: Q_{sum} – Blederija stream flow, Q_{cold} – Blederija cold spring Q_{mix} – Blederija mixed spring

Moreover, the slope of autocorrelogram Q_{cold} initially drops quickly for less than 15 days, and afterwards the same trend remains. This bimodal behavior indicates the duality of the outflow regime. The same is observable for autocorrelograms of Q_{sum} and Q_{mix} (but less pronounced), also indicate a zone frequent mixing of water with “normal” and subthermal waters.

The bivariate analysis considers transformation of the input to the output signal. The cross-correlation function (CCF) of the Blederija source for all considered components (Fig 5.) shows non-symmetrical behavior and relatively high level of influence of effective precipitation on outflow components, particularly within initial time lag (5 day), suggesting that all of analyzed components recharges from binary karst system. A function for all three outflow components becomes insignificant after 55 days, and afterwards it exceeds the level of significance as the consequences of influences of the Q_{mix} components, and specific into the hydraulic behavior of the outflow components. Constant variation of crosscorrelation functions implies non-homogenous karst hydrogeological system, with different responses in various parts of the systems with frequent interchanges of “normal” with subthermal waters. Relatively strong influence of the effective precipitation on Q_{mix} component, similar to the Q_{cold} component, indicates a process of continuous interference of “normal” and subthermal waters. Moreover, common attenuation effect for Q_{mix} component is not quite obvious, and suggest of possibilities of development of the different level of the karst channel system (upper and lower).

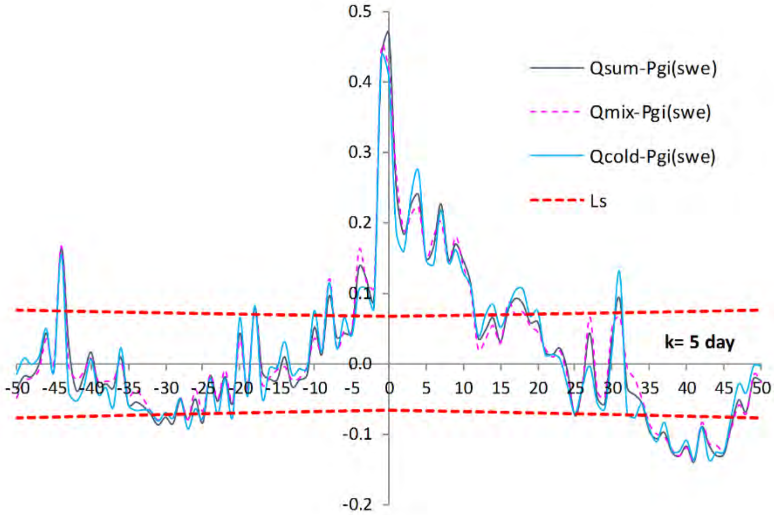

Fig. 5 Cross-correlation function of effective Precipitation and flow components of the Blederija karst source
Legend: Pgi(swe) – effective precipitation – transformed from the measured values to corrected of the wind influence and intercepted by vegetation, and finally melted snow.

CONCLUSIONS

Applied analysis and field exploration were complementary, and in order to obtain conceptual model neither approach could be used solely. There is no doubt that waters from the higher parts of groundwater system have an effect on the decrease in temperature of the lower subthermal groundwater system. Moreover, specificity of this karst hydrogeological system is the existence two independent upper groundwater karst systems, coming from north and from the east, and only the east system has an effect on lowering of water temperature of the subthermal spring. Therefore application of field techniques such as the dye test, still denote one of the irreplaceable techniques in the exploration of the karst hydrogeological system. The complex relation between the cold and the subthermal groundwater in different groundwater stages is presented on the conceptual model.

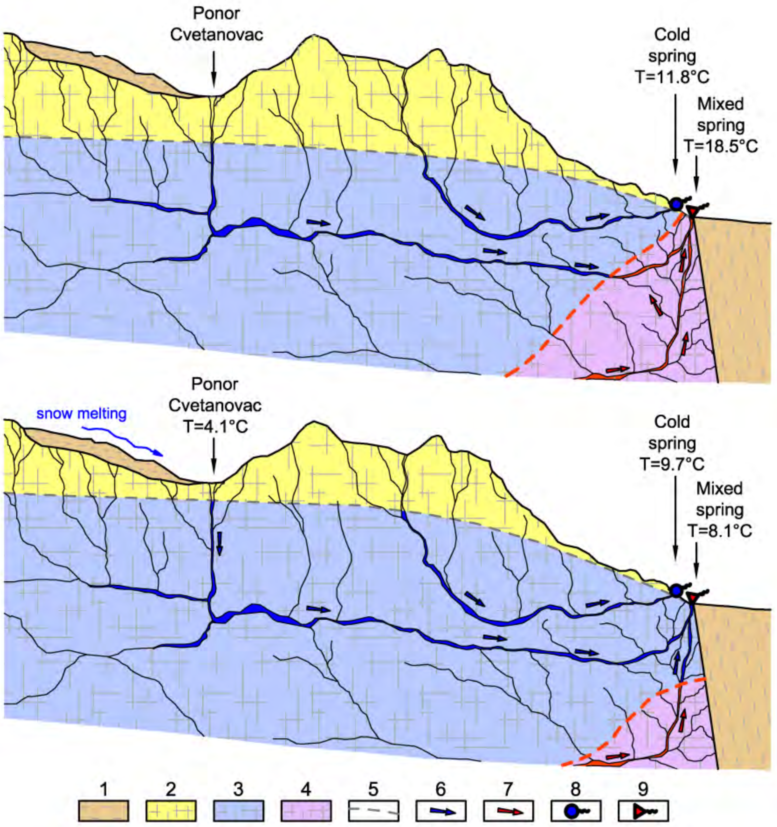

Fig. 6 Conceptual model of Blederija spring discharge during the low (up) and high (down) water regime. (1) low permeable rocks, (2) karstified limestone (vadose zone), (3) karstified limestone (saturated zone with cold water), (4) karstified limestone (saturated zone with thermal water), (5) groundwater level, (6) cold groundwater flow direction, (7) thermal groundwater flow direction, (8) cold spring, (9) mixed spring.

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