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Analysis of discharge conditions of Mokra and Divljana karst springs (SE Serbia)

Анализ на условията за разтоварване на карстовите извори Мокра и Дивляна (ЮИ Сърбия)

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Functioning of a karst hydrogeological system can be explained by analyzing karst spring hydrograph. Having in mind that karst springs are the only visible and often easily accessible part of a karst aquifer, it is important to set up a monitoring network for continuous measurement of the karst spring discharge. Insight into the functioning of a karst hydrogeological system can be provided by analyzing the behavior of karst aquifer discharging in recession conditions, i.e. in the period when karst aquifer has no recharge (Marinović, Petrović, 2018). As already mentioned, continuous monitoring is one of the most important components in the analysis of hydraulic mechanism of discharge of karst springs, which can help us to properly evaluate groundwater reserves. Continuous discharge monitoring at karst springs is not only required to assess groundwater balances, but also delivers hydrographs that are invaluable tools in karst hydrogeology, particularly in combination with chemographs (Goldscheider, 2015).

Several karst springs of Suva Planina Mt. in SE Serbia have been captured for water supply of the cities: Niš, Bela Palanka, Gadžin Han and Babušnica and neighboring villages. Nevertheless, quantitative monitoring of groundwater is not continuous, while qualitative monitoring of groundwater is much more consistent. This paper discusses two case examples from Suva Planina Mt., where Mokra and Divljana karst springs’ discharge were monitored (Fig. 1). Mokra and Divljana karst springs have been captured for water supply of the city of Niš since 1988. Both karst springs emerges at the contact of Lower Cretaceous

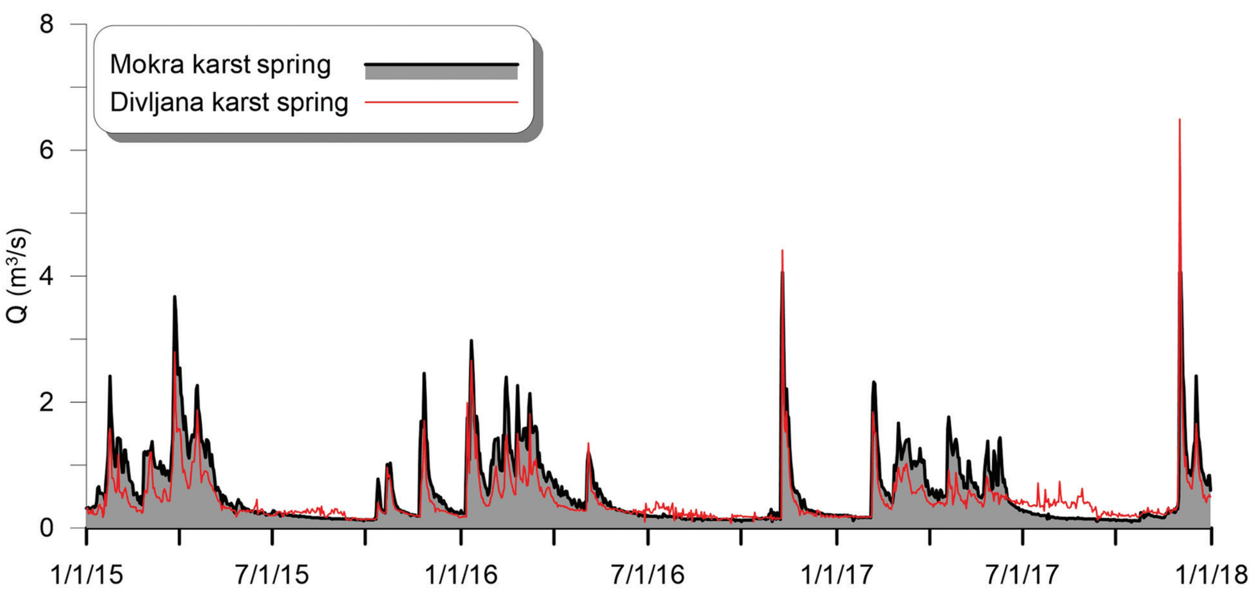

Fig. 1. Hydrographs of Mokra and Divljana karst springs

limestones and Oligocene sediments, influenced by regional and local tectonic.

The analysis of the extreme values of karst spring discharges for period 2015–2017 has showed that the Mokra karst spring has more consistent discharge in the course of a hydrological year – $Q_{max}:Q_{min} = 38:1$, while maximal discharge is around 4.5 m^3/s. Mokra karst spring has two periods of "high" waters, the first one starting in the middle of winter and the second one at the autumn. Divljana karst spring is much more unpredictable (Divljana means Wildly, in Serbian) with maximum and minimum discharge ratio of $Q_{max}:Q_{min} = 85:1$, with maximum discharge values in spring and autumn. Divljana karst spring reached the maximum discharge during period of research ($Q_{max} = 6.492$ m^3/s) in 2017, while minimum discharge value ($Q_{min} = 0.075$ m^3/s) occurred in 2016.

The recession analysis was applied separately for 2015, 2016 and 2017 for both karst springs by using the Maillet's exponential equation (Krešić, 1997). The analysis of the Mokra karst spring has shown the existence of 3 micro-regimes of discharge in 2015, which lasted for 98 days, 2 micro-regimes of discharge in 2016 (lasted 88 days), and 4 micro-regimes of discharge in 2017 lasted 137 days. The volume of discharged groundwater during the recession period was 1.93×10^6 m^3 in 2015, 1.56×10^6 m^3 in 2016 and 4.28×10^6 m^3 in 2017. On the other hand, the recession analysis of the Divljana karst spring shows that recession in 2015 had 2 micro-regimes that lasted 33 days in total, 2 micro-regimes that lasted 44 days in 2016, and finally 3 micro-regimes that lasted 50 days in 2017. The volume of discharged groundwater during the recession period was 1.64×10^6 m^3 in 2015, 2.1×10^6 m^3 in 2016 and 2.21×10^6 m^3 in 2017. Further analysis of recession period showed that the Mokra karst spring has better retention characteristics than Divljana karst spring. One of the facts that supports this is the duration of the last micro-regime of the recession periods. The last micro-regime of the Mokra karst spring is longer than total recession period of Divljana karst spring each year.

The layout of the influence of the surface agents on the karst groundwater area in the case of gravitational and siphoned circulation could be noticed in the behavior of the karst springs (Fig. 2). In the conceptual model of draining and circulation of the karst springs (Vasić et al., 2013, 2015) one can notice gravitational circulation with rapid water exchange and large cavities (Zone 1), then siphonal circulation with rapid water exchange as well as drainage channels of moderate size (Zone 2) and finally siphonal circulation with slow water exchange and small dimension of drainage channels, fissures and voids (Zone 3).

The longer recession of the Mokra karst spring could relate to the presumption of existence of larger aquifer that is drained and existence of siphonal groundwater circulation through deep and shallow

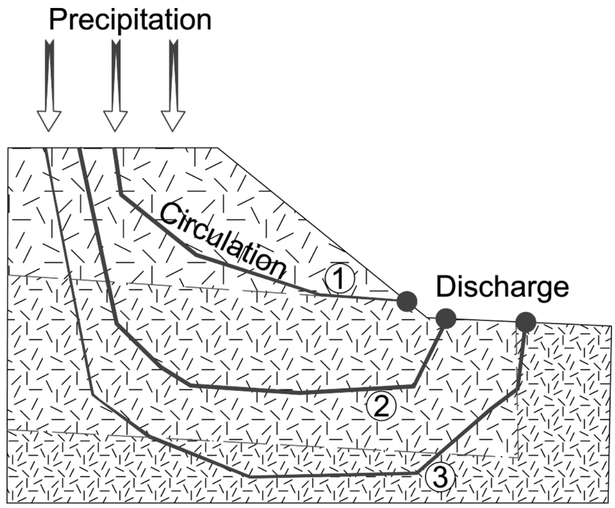

Fig. 2. Conceptual model of draining and circulation of the karstic springs: *1*, gravitational circulation; *2*, siphonal circulation/rapid water exchange; *3*, siphonal circulation/slow water exchange (after Vasić et al., 2013, modified)

karst conduits (Zone 3 and 2 at Fig. 2). On the other hand, the analysis of the Divljana karst spring discharge behavior in recession period shows the existence of the shallower karst siphonal channels (Zone 2) connected with gravitational circulation (Zone 1).

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