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Предварителен анализ на изтичащите водни количества от извора Крупая (Източна Сърбия)

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Karst aquifers are among the highest-quality water sources for public water supply. In Serbia, they are found in carbonate rocks in the eastern and western parts of the country. These karst aquifers are formed in open karst structures and well-karstified rocks, with a highly developed network of fractures, caverns and conduits. The karst aquifer regime is largely dependent on the pluviographic regime (rain, snow) and that is why they appear to be highly vulnerable to climate change. It should be noted that the karst massifs that host karst aquifers have a high potential for static and dynamic groundwater reserves. As a result of specific geologic, structural geologic and hydrogeologic conditions, the aquifers are drained by springs whose discharges are generally not uniform. Sufficiently long discharge time-series of the karst springs that drain a karst massif and good coverage of the massif by rain gauges/weather stations are required to determine karst groundwater reserves. In Serbia, the Mlava Spring (in Serbian Vrelo Mlave) has been monitored since 1949. Other springs were observed sporadically and over short periods, through to the year 2014. Rain gauge or weather station coverage is also an issue. Since the area is sparsely populated, it has not been possible for the National Hydrometeorological Service (RHMZ) to engage observers for daily precipitation monitoring. It is only in the 21st century that automated stations are becoming part of the meteorological network.

An adequate monitoring network is required to determine the discharge regimes of karst springs. On 23 October 2000, the European Union Parliament and Council adopted the Water Framework Directive (WFD, 2000), which established a new long-term water management policy. The main WFD objective is to achieve "good status" of all natural water bodies, or good chemical and ecological status of waters (Nikolić et al., 2019). In Serbia, the Surface Water and Groundwater Bodies Delineation Code (2010) serves as the basis for groundwater monitoring. It introduced the concept of groundwater bodies, which it describes as separate volumes of groundwater within one or more water-bearing layers. Following delineation, 153 water bodies have been identified in Serbia (Nikolić et al., 2012).

The establishment of groundwater monitoring, which had not been on an enviable level before the WFD, became a priority. In the latter half of 2014, RHMZ began to monitor the discharges of major karst springs, including the Krupaja Spring (in Serbian Krupajsko Vrelo), which is the topic of this paper. Several years earlier, the Department of Hydrogeology (DHG) of the University of Belgrade Faculty of Mining and Geology began observing and gauging the Krupaja Spring for the purposes of the international project "Climate Change and Impacts on Water Supply/CCWaterS" (Stevanović et al., 2012). The main objective was to study groundwater availability and conservation for sustainable public water supply. Different climate change scenarios were assessed. The selected study area was the karst massif of Mt. Beljanica and monitoring included the major karst springs of the massif (Krupajsko Vrelo, Belosavac, Suvi Do, Živkova Rupa, Mlava, Veliko Vrelo and Malo Vrelo). The project lasted from 2009 to 2012, but DHG has continued to monitor the springs. As a result, 11-year time-series of daily discharges have been generated. There have been multiple extreme hydrologic (wet and dry) episodes in the past two decades, so the time series include the extremely wet year 2014 (with record discharges and river stages registered by many

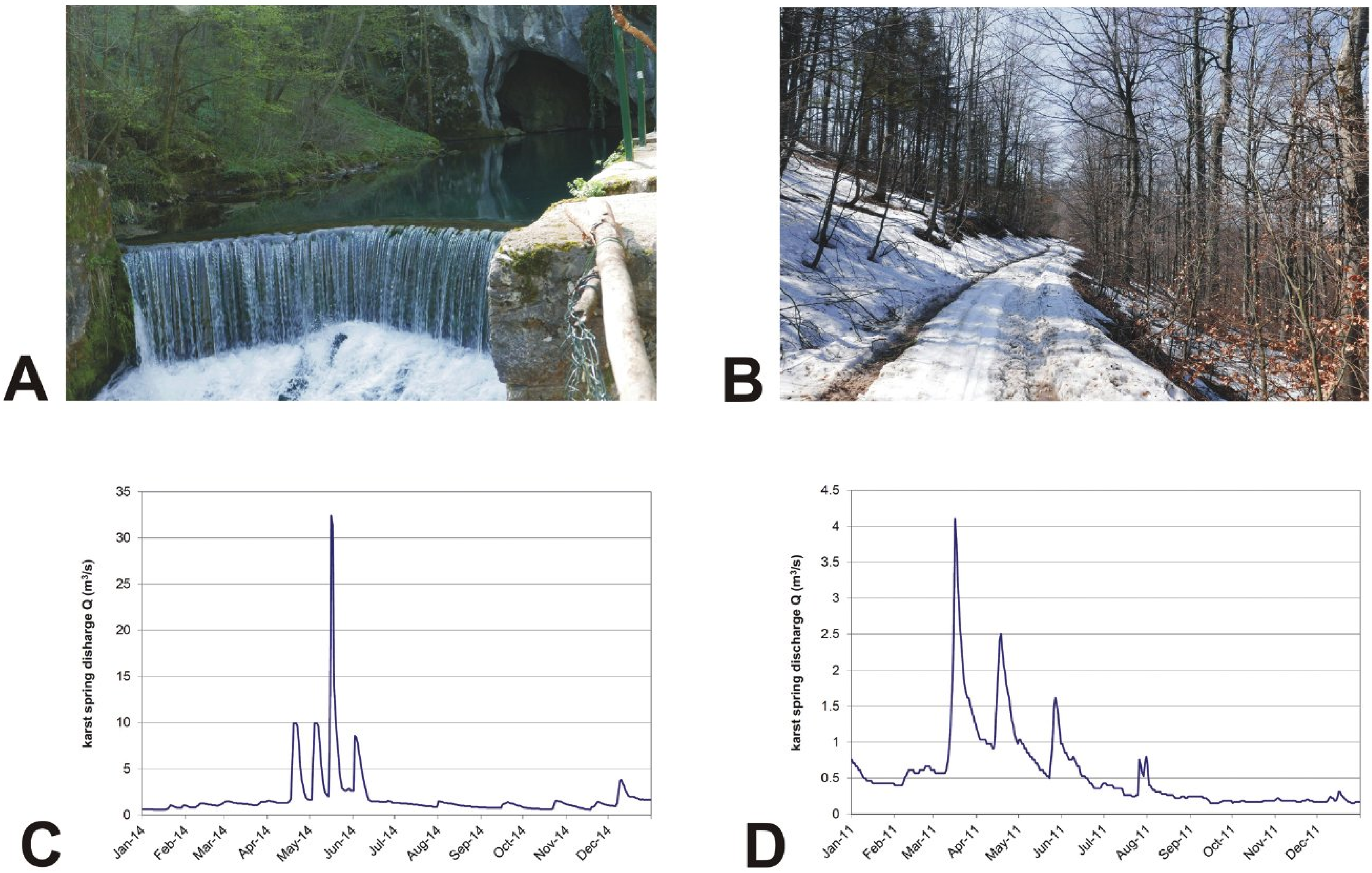

Fig. 1. *A*, Krupaja Spring; *B*, part of Krupaja Spring catchment (April, 2019; *C*, Krupaja Spring hydrograph of typical wet year; *D*, Krupaja Spring hydrograph of typical dry year

gauging stations), as well as the period 2011–2013 that was extremely dry. The paper discusses the discharges of the Krupaja Spring and focuses on extreme events.

The Krupaja Spring is located on the western foothills of the Beljanica karst massif, at an elevation of 215 m (Fig. 1a). It is the source of the Krupaja River (in Serbian Krupajska reka), which is the largest tributary of the Mlava River. The spring is 2 km from the center of the village of Milanovać that is 25 km from the town of Žagubica. The spring is of the deep syphonal type, where any variation in the vertical morphology of the contributing conduits has a considerable effect on the discharge regime (Milanović, 2010). The karst aquifer is recharged by precipitation infiltrated through ponors, sinkholes, and fractures of various sizes, as well as water from surface streams and groundwater from other aquifers (Nikolić, 2019).

The pluviographic regime was studied to gain the best possible insight into the general water balance. Recharge of the studied aquifer comes from snowmelt, which is considerable in this karst massif, as well as long episodes of heavy spring rains. Figure 1b shows the weather conditions on Mt. Beljanica (Krupaja Spring catchment). The plot was generated in April 2019 and serves as evidence that due to low temperatures, the snow cover melted in late spring (March and April). This led to similar changes in the discharge hydrographs, with several peaks during that period due to sudden snowmelt and/or heavy spring rain episodes. By contrast, there were long recession periods in summer and autumn.

In view of the fact that water level and discharge monitoring by DHG provided a longer time-series, the analysis presented below pertains to that discharge data. The years 2014 (extremely wet, Fig. 1C) and 2011 (typical dry, Fig. 1D) were selected for regime analysis.

In 2014, the mean annual discharge was 1.903 m^3/s and in 2011 only 0.57 m^3/s. The daily discharges of the Krupaja Spring in 2011 ranged from 150 l/s to 4.1 m^3/s and in 2014 from 0.57 m^3/s to 32.4 m^3/s. It should be noted that the absolute minimum discharge in 2014 equaled the mean annual discharge in 2011. Before 2011, the absolute minimum discharge (based on sporadic gauging) was believed to be 220 l/s and the maximum up to about 10 m^3/s (or not much higher). The data collected in 2011 showed that the absolute minimum was actually only 150 l/s. The discharge of as much as 32.4 m^3/s, recorded on 16 May 2014, is deemed the record high of the spring. Even though the spring was not continually monitored before August 2009, information was gathered from people who have lived near the spring for decades. They did not know what the record discharge was, but they did know how high the water level of the spring pool had risen in the past and it was never to the elevation recorded in 2014.

The paper aims to point out how important it is to monitor hydrogeologic features, primarily springs. Discharge monitoring is often not easy to arrange because of the location of a karst spring. On the other hand, since karst massifs are generally unpopulated, there is no industry. If there is any farming, it is sparse and of a rural nature. Major roads tend to bypass karst massifs, not run over them, so karst groundwater is not at risk of accidental pollution. Consequently, these high-quality waters, which require only chlorination for public water supply, flow uncontrolled and virtually no quantity data is available. One-year quantity and quality monitoring for specific studies or reports required by law is not sufficient to examine all the parameters that would indicate the extent of dynamic reserves.

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