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Въздействие на карстовите води върху повърхностния отток: пример с водосбора на река Ресава, Сърбия

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Abstract. The paper compares the flow regimes of the Resava River at the gauging stations of the Manasija Monastery (upper course) and the town of Svilajnac (lower course). The hydrological analysis encompasses a multiyear period of monitoring (1982–2020). The water budget and baseflow index are assessed for the catchment areas monitored by the Svilajnac station (683 km^2) and the Manasija Monastery station (358k m^2), considering the overall monitoring period and characteristic years. The results indicate that the specific runoff in the upper catchment is about 50% higher than that of the entire catchment. The reason is that the upper catchment is 55 % karst, whereas the remainder is non-karst. The situation is similar in dry years. However, in wet years the specific runoff of the entire catchment is higher than that of the upper catchment.

Keywords: hydrogeological characteristics, water regime, water balance, karst aquifer, Resava catchment area.

Introduction

The Resava catchment is in the northern part of Eastern Serbia, between the Velika Morava River and the slopes of the Kučaj-Beljanica Mountains. The Resava River originates at the junction of the Zlotska River and the Karapandžin Creek at an altitude of 668 m. It is a major right-side tributary of the Velika Morava (Dukić, Gavrilović, 2014). The total length of the Resava is 65.5 km and its catchment area (according to the National Hydrometeorological Service) is 681 km^2. It generally flows in the SE-NW direction, all the way to its mouth near Svilajnac, where the elevation is 93 m. The upper catchment of the Resava is a composite valley comprised of gorges, ravines, and canyons (mostly karst), which enters the Velika Morava River Basin near the town of Despotovac (Paunković, 1953). The upper Resava runs from the village of Strmosten in the west and the village of Tresta in the east, an area between the southwestern part of Mt. Beljanica (1339 m) and the northwestern part of the Kučaj Mountains (1284 m). The Resava Gorge was formally designated as a protected area in 1955, as part of the Upper Resava Regional Nature Park. The area hosts several natural features with the status of nature monuments, including Vintovača (nature preserve), Lisine (Veliko Vrelo, Veliki Buk – hydrological nature monument), Radoš Cave, Resava Cave, Bašan Kamen, and Vrtačelje (Avramović, 2005).

Hydrogeological characteristics of the Resava catchment

Based on the lithostratigraphic units and structural porosity, there are three types of aquifers in the study area.

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1. *Intergranular aquifers* in the central and western parts of the study area, formed in Quaternary and Neogene sediments. They are recharged by infiltration of precipitation, water from surface streams, and in part by karst aquifer groundwater. They are drained directly into the river, generally during dry periods, but largely by wells that service public and industrial water supply, as well as local, mostly shallow dug wells used for a farmland irrigation.

2. *Fractured aquifer* found along the western fringes of Mt. Beljanica, in the central part of the study area. It is associated with red Permian sandstones and dacites of the Krepoljin-Senj zone. Favorable filtration features are attributable to direct tectonic contacts with limestones.

3. *Karst aquifer* in the eastern, upper part of the catchment, characterized by favorable filtration properties. Groundwater flows in developed systems of fractures and caverns. This aquifer is recharged by infiltration of precipitation and water from sinking streams. It is discharged via springs, groundwater flow into adjacent semi-permeable sediments, and in part by evapotranspiration. Springs are generally found at points of contact between carbonate and non-carbonate rocks, and their positions are governed by fault structures and fracture systems.

4. In addition to these aquifer types, there are "conditionally waterless" parts of the terrain, with rocks, which hydrogeological properties are not conducive to the formation of aquifers.

Flow regime of the Resava River

The following characteristic years were selected to show the flow regime of the Resava River:

- Years in which the mean annual discharge was equal to the multiyear average: 2001 (Qav = 3.48 m^3/s at Manasija Monastery and Qav = 4.35 m^3/s at Svilajnac) and 2018 (Qav = 4.06 m^3/s at Manasija Monastery and Qav = 4.65 m^3/s at Svilajnac (Figs. 1a, 1b);
- The year 1994 with a typical low discharge: Qav = 0.58 m^3/s (at the Mansija Monastery) and 0.33 m^3/s (at Svilajnac) (Fig. 1c); and
- The year 1999 with the highest discharge: annual average 14.64 m^3/s at the Manasija Monastery and 18.9 m^3/s at Svilajnac (1:1.3).

In addition to hydrographs (Fig. 1a–d), the coefficients of correlation are indicative of the correspondence of the discharges recorded at the upstream and downstream gauging stations. They range from 0.878 in the wet year, 0.91 and 0.942 for the years, when the mean annual discharge was

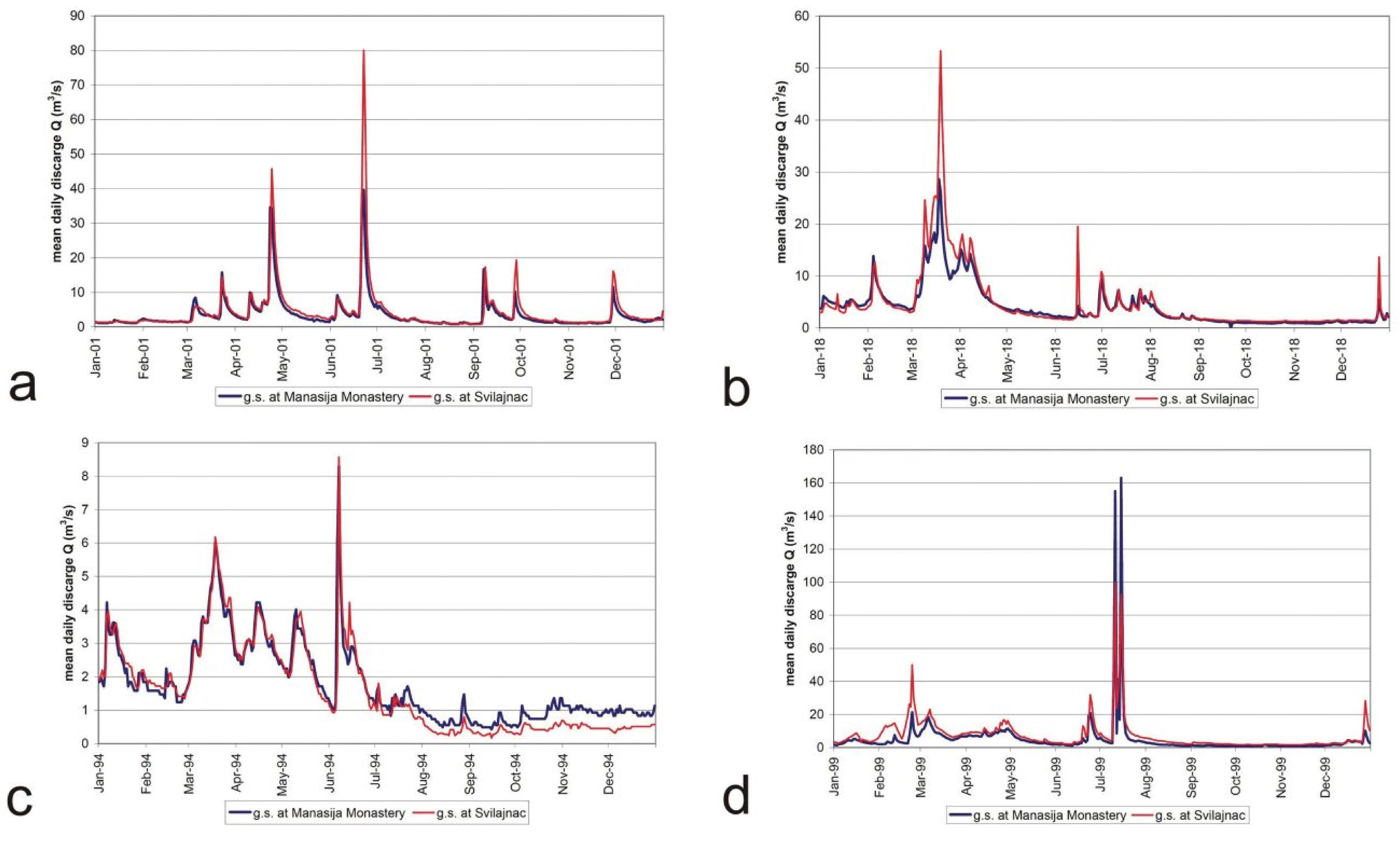

Fig. 1. Catchment of the Resava River and parallel discharge hydrographs of characteristic years: (*a*) and (*b*) years in which the mean annual discharge was equal to the multiyear average, (*c*) year with a typical low discharge, and (*d*) year with the highest discharge

equal to the multiyear average, to 0.965 in the dry year.

The hydrographs show that the ratio of mean annual discharges is 1:1.25 (2001) and even lower in 2018 (1:1.15). The ratio of the catchment areas covered by the gauging stations is 1:1.75. This suggests that most of the discharge of the Resava River is formed in the upper catchment (Figs. 1a,b). In the case of the characteristic low mean annual discharge, the ratio was 1:0.57 in 1994, meaning that during dry periods the annual discharges are lower at the downstream station than the upstream station. This can also be observed in the hydrograph (Fig. 1c), where the discharge of the Resava River during the recession period is much higher at the Manasija Monastery than at Svilajnac. There are several possible reasons for this, primarily the use of surface water for a farmland irrigation, which is more intensive in dry years. Also, a higher rate of the groundwater abstraction during such periods lowers the water table and intensifies aquifer recharge from the Resava River. Furthermore, high temperatures and decreased depths of the river in dry years increase the evaporation, resulting in higher discharges upstream than downstream. There is a good correlation between discharges in wet years but according to records, at the beginning of July 1999 the discharge at the Manasija Monastery was about 60 m^3/s higher than at Svilajnac, which is impossible. The reason for this deviation might be that the flood curve was not well defined (less likely) or that the Resava River burst its banks at the Manasija Monastery and flooded the lower catchment of the Resava, which physically caused the stages at Svilajnac to be lower than realistic and the calculated discharge to also be lower. Thich was most probably the case in 1999.

The baseflow and direct flow in the selected years, observed at the two gauging stations, were separated to analyze the flow regime. Table 1 shows discharge volumes for baseflow and direct flow (10^6 m^3), as well as the baseflow indices (BFI). In the selected years, the BFI at the Manasija Monastery was 3 to 9% higher, suggesting that the karst massif had considerable dynamic reserves, which recharged the Resava River during dry periods. The year 2001 was an exception, when the situation was the opposite. Namely, the BFI was higher at Svilajnac. There are several potential reasons for this, and the most likely cause was a recharge of the alluvium on account of rainfall episodes. This assumption is supported by the rainfall recorded in 2001 at the Crni Vrh weather station that covers the upper catchment and the Smederevska Palanka weather station that monitors the lower catchment. In 2001, the Crni Vrh weather station recorded 726.1 mm, which was 40.2 mm lower than the multiyear average, while the Smederevska Palanka weather station registered 760 mm, which is 111 mm higher than the multiyear average and 34 mm higher than at Crni Vrh.

The above-mentioned weather stations were reference stations for the calculation of water balance equation parameters. Given that these two stations were characteristic of the highest and lowest elevations of the Resava catchment, the analysis considered the arithmetic mean of the precipitation typically recorded by the stations, which amounted to 707.5 mm. A similar approach was followed for the selected characteristic years, such that the annual precipitation totals of the Resava catchment were 570 mm in 1994 (dry year) and 902.4 mm in 2010 (wet year). On the other hand, the values observed at Crni Vrh were used as reference values for the catchment area monitored by the gauging station at the Manasija Monastery, for the multiyear period as well as the dry and wet years.

The resulting values for the part of the catchment monitored by the gauging station at the Manasija Monastery show that the upper catchment of the Resava River conveys 3.31 m^3/s or 104 million cubic

Table 1. Baseflow and direct flow volumes and baseflow index

Year	Gauging station	W_{total}	$W_{baseflow}$ (10^3 m^3)	$W_{direct\ flow}$ (10^3 m^3)	Baseflow index
1994	Manasija Mon.	55.597	38.176	17.423	0.687
1994	Svilajnac	50.607	33.697	16.912	0.666
1999	Manasija Mon.	159.214	78.198	81.017	0.491
1999	Svilajnac	233.635	110.095	123.540	0.471
2001	Manasija Mon.	109.352	48.060	61.292	0.439
2001	Svilajnac	136.921	65.832	71.089	0.481
2018	Manasija Mon.	128.037	94.993	33.046	0.742
2018	Svilajnac	148.027	100.627	47.512	0.680

meters of water annually. Regarding water availability, the value of 9.25 l/s/km^2 is considerably above Serbia's average. In dry years, the specific runoff is somewhat lower than the country's average (4.92 l/s/km^2). However, in wet years it is 2.3 times higher. When the two values of specific runoff are compared, the upper catchment's specific runoff is generally ca. 50% higher than that of the entire catchment. The reason is that 55% of this part of the catchment is a karst terrain, and the rest is non-karst. The same applies to dry years but in that case the specific runoff in the upper catchment of the Resava River is twice the specific runoff in the entire catchment in the same dry year, or the area covered by the gauging station at Svilajnac. However, in wet years the situation is opposite. The specific runoff of the entire catchment is higher than that of the upper catchment. This is attributable to the fact that part of the rainfall is infiltrated into the karst massif and remains there as dynamic karst groundwater reserves. In contrast, after a heavy rainfall in the lower catchment, the soil likely becomes saturated and causes swelling of the clay component of the Miocene sediments, forming a less permeable surface layer during such periods and a large portion of the rainfall runs off to the main drain – the Resava River.

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