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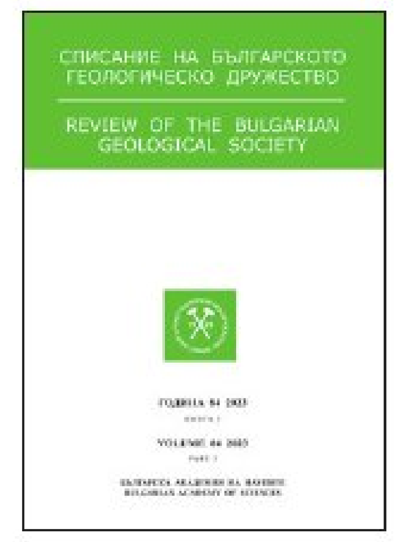

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A contribution to the understanding of the discharge dynamics and water balance of the karst spring Gornji Dušnik (Suva Planina)

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Принос към разбирането на динамиката на оттока и водния баланс на карстовия извор Горни Душник (Сува планина)

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Abstract. A sufficiently long time-series of daily discharges is needed to assess the discharge dynamics and calculate the water balance equation parameters of a spring (river source). The paper assumes that a catchment is gauged if a time-series of observations of at least 30 years is available, which is a rare case in Serbia. One-year monitoring is often set up to verify the reserves of a water source or spring intended for capture. Monitoring ceases after the final report is produced. The paper aims to show potential problems if there are no sufficiently long time-series and if no detailed hydrogeological investigations have been undertaken. The Gornji Dušnik Spring is used as an example. That spring drains the western parts of Suva Planina Mountain. It was captured many years ago to provide public water supply to the town of Gadžin Han and the nearby villages of Donji Dušnik and Gornji Dušnik.

Keywords: discharge dynamics, water balance, catchment area, karst spring Gornji Dušnik, Suva Planina.

Introduction

When the catchment of a spring in karst is examined, the most frequent challenge is to define the underground water divide and calculate the actual catchment size. In such cases one often takes the easy way out and defines the surface water divide (or surface catchment area). This approach can be misleading and can affect the calculated water balance equation parameters to a significant extent. A good example is the Žrnovica Spring, whose topographic catchment area is only 8.4 km^2, but whose real hydrogeological water divide is about eight times larger (Bonacci, Andrić, 2015). Another problem is a too short time-series of discharge observations because it can lead to wrong conclusions. For example, if there is a time-series of one year, recession analyses will yield different results depending on whether the year was wet or dry. Finally, insufficient coverage by rain gauge or weather stations in the part of the catchment where most of the recharge occurs and relying on data from stations at much lower elevations can also affect the analysis and its results (Ristić Vakanjac et al., 2016).

The karst spring Gornji Dušnik (Fig. 1) was selected to illustrate all the above. The spring drains the western parts of Suva Planina (Eng. Dry Mountain). The importance of the spring lies in the fact that it has been captured to provide public water supply to the town of Gadžin Han and the villages of Donji Dušnik and Gornji Dušnik. The study area belongs to the catchment of the Kutina River, which empties into the Nišava River. The Nišava joins the Južna Morava, which belongs to the Velika Morava

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River Basin. The Velika Morava empties into the Danube River at Smederevo. Broadly speaking, all these rivers fall within the Black Sea Basin.

The catchment of the Gornji Dušnik Spring is largely characterized by a temperate continental climate, meaning cold winters and warm summers. Mountain climate conditions are registered at higher elevations. The precipitation regime needed to be analyzed first, in order to calculate the water balance equation parameters. Data from five rain gauge stations were used. The stations are part of the monitoring network of the Hydrometeorological Service of Serbia (RHMZ) and they include the stations set up at Niš (alt. 204 m), Glogovac (310 m), Bela Palanka (290 m), Babušnica (495 m), and Donja Koritnica (400 m).

Analysis of monitoring data

Based on the monitoring period from 1960 to 2020, the multiyear average precipitation ranges from 601 mm (weather station at Niš) to 693.5 mm (rain gauge station at Donja Koritnica). Keeping in mind the various altitudes of these stations, precipitation increases with altitude by about 30 mm per 100 m on average (Fig. 1a). With regard to the monthly distribution, the wettest months are May and June and the driest February and August to October. The highest mean monthly precipitation of the five stations was recorded in June (69.38 mm) and the lowest in February (45.45 mm).

The Gornji Dušnik Spring drains the western fringe of the Suva Planina Mountain. The spring is located at the point of contact between Tithonian–Valanginian carbonate rocks and Aptian sandstones of a regional dislocation (the Dubrava fault) trending NW-SE, along which the western block (Aptian sandstones) had collapsed. The groundwater level of the aquifer is very steep behind the discharge zone, where there are thick calc-sinter deposits (Fig. 1b).

There has been no continuous monitoring of the Gornji Dušnik Spring to the present day. There were only two observation campaigns of less than 18 months each. The first campaign was launched by Geozavod from Belgrade and data was collected once in five days from November 1977 to January 1979. The minimum discharge during that period was recorded on 21 December 1977, amounting

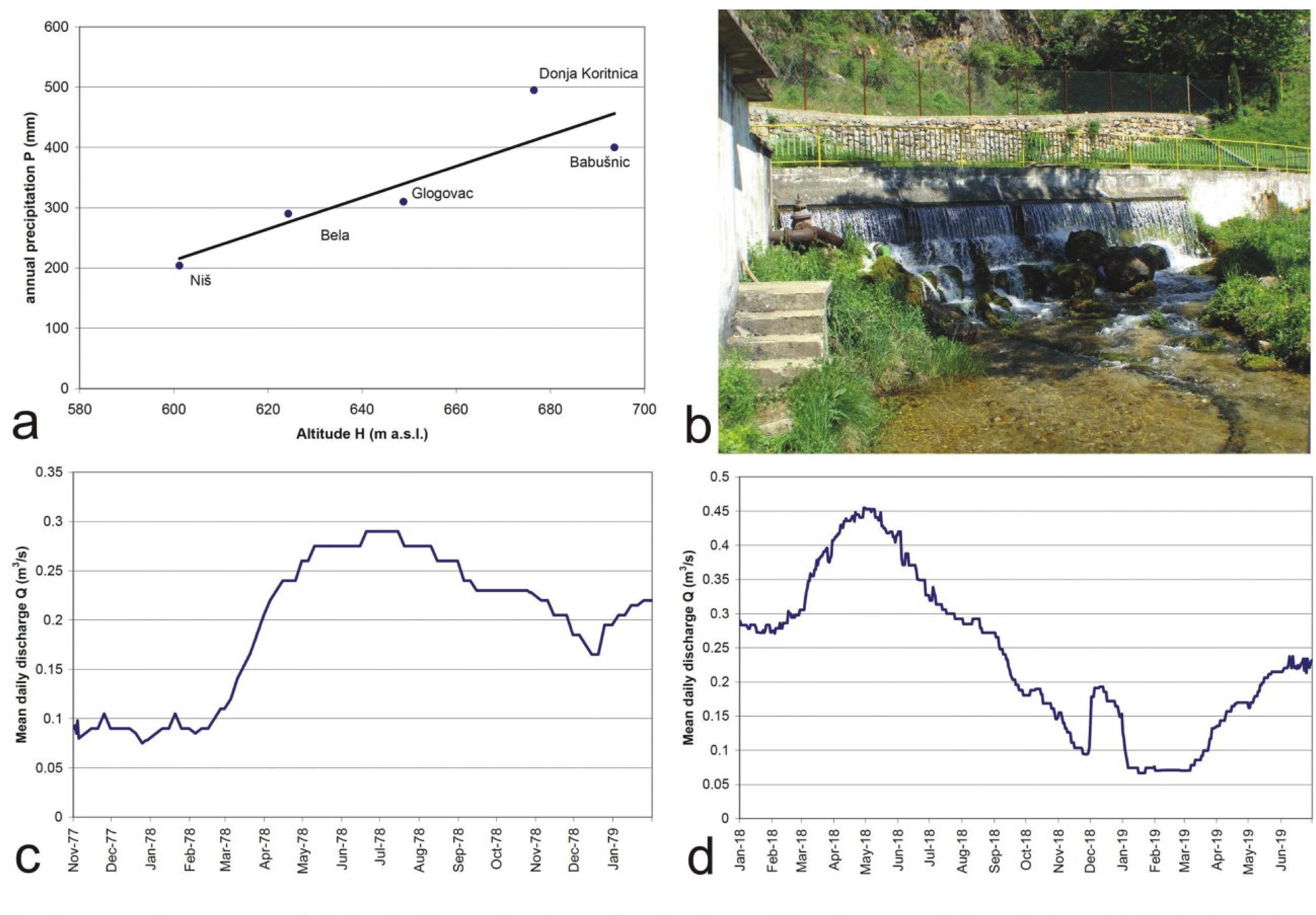

Fig. 1. *a*, annual average precipitation totals as a function of the elevations of the rain gauge stations that provided data; *b*, photo of the Gornji Dušnik Spring; c, mean daily discharges of the Gornji Dušnik Spring from 1 Nov. 1977 to 31 Jan. 1979; *d*, mean daily discharges of the Gornji Dušnik Spring from 1 Jan. 2018 to 30 June 2019

Table 1. Elements of the Gornji Dušnik Spring water balance for I and II periods

Period	F	P	E	h	Q_{av}	q	W	φ
	km^2	mm	mm	mm	m^3/s	$l/s/km^2$	$10^6\ m^3$	
Period I	10.6	801	185.2	615.8	0.207	19.53	6.528	0.77
Period II	10.6	532	–155.2	687.2	0.231	21.79	7.285	1.29
Calculated water balance equation parameters for a catchment size of 20 km^2								
Period I	20	801	474.6	326.4	0.207	10.35	6.528	0.41
Period II	20	532	167.8	364.2	0.231	11.55	7.285	0.68

to 75 l/s. The maximum discharge was registered from 22 June to 17 July 1978, and it amounted to 0.29 m^3/s (Fig. 1c). The average for the period was 0.207 m^3/s. The second monitoring campaign was from January 2018 to June 2019, launched by the Department of Hydrogeology of the University of Belgrade, Faculty and Mining and Geology. The maximum discharge recorded during that period was 0.454 m^3/s (29th April 2018) and the minimum discharge 0.067 m^3/s (17th January 2018) (Fig. 1d). Reference precipitation levels were calculated for both periods of observation, using data from the weather station at Babušnica. It amounts to 804 mm for Period I and 532 mm for Period II.

Based on the annual average discharges of the Gornji Dušnik Spring and the characteristic annual precipitation in the study area, the calculated water balance parameters are as shown in Table 1. The following equations were used to arrive at the result: multiyear average volume of water available in the catchment:

$W = \overline{Q} \cdot 31.536\ (10^6\ m^3)$;

multiyear average runoff layer: $h = \frac{1000 \cdot W}{F}$ (mm);

evaporation: $E = P - h$ (mm);

specific runoff: $q = \frac{Q}{F}$ ($l/s/km^2$),

and multiyear average runoff coefficient $\varphi = \frac{h}{P}$.

Conclusions

The following conclusions can be drawn from the results presented in Table 1.

1. Considering the annual average discharges and the annual average precipitation recorded by the weather station at Babušnica, even though precipitation in Period I was 269 mm (about 50%) higher, spring discharge was 24 l/s (11%) lower. This suggests that the results for Period I (Table 1) should be taken with caution because water levels and discharges were observed every 5 to 7 days. This might have affected the calculated discharge values and not rendered the most realistic picture of the spring dynamics. In addition, no snow cover data was available for the study. Given the elevation of the catchment on the Suva Planina Mountain, the snow cover certainly plays an important role in aquifer recharge. *In this regard, spring monitoring needs to continue in order to gain better insight into the discharge dynamics of this spring and the water balance.*

2. The catchment size of 10.6 km^2 was taken from Risimić (2012). It needs to be checked by detailed hydrogeological investigations. Based on the results of the present study, the catchment area is assumed to be larger, but it is not possible to say by how much at this time.

3. The annual average precipitation data used to calculate the water balance equation parameters were taken from the weather station at Babušnica. Apart from the rain gauge station at Donja Kortinica, the station at Babušnica was at a higher altitude than the other stations whose data was analyzed. The rain gauge station at Donja Koritinica was not taken into consideration because data was missing for certain months in Period II. *Data from the rain gauge stations at Donja Koritnica and Glogovac, if the stations are still active, need to be collected to gain better insight into the precipitation regime of the catchment. A weather station should certainly be installed in the catchment of the Gornji Dušnik Spring and an observer engaged to monitor and maintain the station.*

4. Regarding the runoff coefficient of 0.77 for Period I, the value is higher than expected for karst in this part of Serbia. This is attributable to the catchment size, which is assumed to be larger, as well as the precipitation data collected from the station at Babušnica. *An isohyet map should be produced for the defined catchment size and calculations repeated with the average precipitation characteristic of the catchment.*

5. The runoff coefficient of 1.29 for Period II is illogical. It is also likely a result of an incorrectly estimated catchment size and the precipitation typical of a single point (Babušnica), which is not representative of the entire catchment.

6. In essence, the values of specific runoff of 19.5 l/s/km^2 (Period I) and 21.8 l/s/km^2 (Period II) can in some cases be typical of catchments in karst. However, according to Ristić (2007), the average specific runoff of Suva Planina amounts to about 11 l/s/km^2 (a value characteristic of the Mokra and Divljana catchments). This value can certainly be accepted as a characteristic and reference value of the Gornji Dušnik catchment. However, the large difference between the specific runoffs resulting from the present study and those reported in Ristić (2007) also suggest that the catchment size is ill defined. If we accept that the specific runoff of 10.5 l/s/km^2 applies to the Gornji Dušnik catchment, then the catchment area of that spring would be about 20 km^2, which should be verified by detailed hydrogeological investigations.

Table 1 shows the water balance equation parameters for a catchment area of the Gornji Dušnik Spring of 20 km^2, which are deemed to be realistic.

7. In conclusion, please note that the water balance equations pertain to periods slightly longer than one year. In such cases, the variation in the dynamic volume of water in the catchment needs to be included. Since it was not possible to define it for the studied periods, that, too, impacted the calculations. *Long-term monitoring needs to be established and the calculations repeated. Until then, maybe a method can be used for the existing time-series to be extended to cover the period, for example, from 1960 to 2020, and then repeat the calculations. In that case, the variation in the dynamic water volume in the catchment could be disregarded. An isohyet map should certainly be produced for the study period and the multiyear average precipitation totals calculated.*

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