

ЗБОРНИК РАДОВА
ОДБОРА ЗА КРАС И СПЕЛЕОЛОГИЈУ

XI

ACADEMIE SERBE DES SCIENCES ET DES ARTS

ÉDITIONS SPECIALES

Vol. DCXCVIII

DÉPARTMENT DE MATHÉMATIQUE, PHYSIQUE ET GÉOSCIENCES

Vol. 6

RECUEIL DES RAPPORTS
DU COMITÉ POUR LE KARST
ET LA SPÉLÉOLOGIE

XI

Reçu à la I séance du Département de mathématique,
physique et géosciences, le 26 février 2021

Rédacteur

SLOBODAN MARKOVIĆ

Membre correspondant de l'Académie

BEOGRAD 2021

СРПСКА АКАДЕМИЈА НАУКА И УМЕТНОСТИ

ПОСЕБНА ИЗДАЊА

Књ. DCXCVIII

ОДЕЉЕЊЕ ЗА МАТЕМАТИКУ, ФИЗИКУ И ГЕО-НАУКЕ

Књ. 6

ЗБОРНИК РАДОВА
ОДБОРА ЗА КРАС
И СПЕЛЕОЛОГИЈУ

XI

Примљено на I скупу Одељења за математику,
физику и гео-науку, 27. фебруара 2021. године

Уредник

СЛОБОДАН МАРКОВИЋ

дописни члан САНУ

БЕОГРАД 2021

Издаје
Српска академија наука и уметности
Београд, Кнеза Михаила 35

Лектор и коректор
Ана Бардајесковић

Технички уредник
Никола Сивановић

Тираж
300 примерака

Штампа
ЈП *Службени гласник*

ISBN 978-86-7025-897-6

САДРЖАЈ

<i>Предговор</i>	7
Јелена Ђалић: <i>Месиво карстине увале у систему површинских карстних депресија (групи гео)</i>	11
Jelena Ćalić: <i>Position of the Karstic Uvala Within the System of Karst Surface Depression (part two)</i>	28
Бранислав Петровић, Вељко Мариновић, Зоран Стевановић, Саша Милановић, Љиљана Васић: <i>Режим изданских вода карстине у области Бадине (ЈЗ Србија, Пријепоље)</i>	29
Branislav Petrović, Veljko Marinović, Zoran Stevanović, Saša Milanović, Ljiljana Vasić: <i>Groundwater Regime of the Babine Karst Plateau (SW Serbia, Prijepolje)</i>	50
Zoran Stevanović: <i>Karst Aquifers of Southeast Europe – Essential and Rich Resource of Potable Waters</i>	53
Зоран Стевановић: <i>Карстине издани југоисточне Европе – есенцијални и бојати ресурс воде за пиће</i>	67
Драган Нешић: <i>Резултати обележавања њонора у сливу Прлитске реке (Вршка чука, источна Србија)</i>	69
Dragan Nešić: <i>Results of Tracing Tests in the Prlitska Reka River Catchment (Vrška čuka, Eastern Serbia)</i>	81
Rajko Dimitrijević: <i>Description of the Female of Cave-Dwelling Pseudoscorpion Neobisium rajkodimitrijevići Ćurčić, 2006 (Neobisiidae, Pseudoscorpiones) from Serbia</i>	83
Рајко Димитријевић: <i>Опис женке пећинске врсте Neobisium rajkodimitrijevići Ćurčić, 2006 (Neobisiidae, Pseudoscorpiones) из Србије</i> ...	90

Весна Димитријевић: Кључна дојуна фаунистичке секвенце средњи-касни плейстоцен Србије: остаци сисара из наслаја пећине Пештиурина (Јелашиница, источна Србија)	91
Vesna Dimitrijević: Key Addition to Faunal Sequence of Middle-Late Pleistocene of Serbia: Remains of Mammals from the Deposits of the Cave of Pešturina (Jelašnica, Eastern Serbia)	100
Милорад Кличковић: Посећености туристичких пећина Србије у периоду од 2005. до 2015. године	103
Milorad Kličković: Attendance to Show Caves in Serbia in the Period 2005–2015.	119
<i>In memoriam</i>	
Професор др Божидар Бурчић (1946–2015)	125
Професор др Боривоје Мијајковић (1931–2018)	135
Професор др Душан Гавриловић (1934–2020)	139

KARST AQUIFERS OF SOUTHEAST EUROPE – ESSENTIAL AND RICH RESOURCE OF POTABLE WATER

ZORAN STEVANOVIĆ*

Abstract. – Southeast Europe (SEE) is abundant with groundwater accumulated in karstic aquifers of numerous mountain massifs of the Alpine orogenic belt and intergranular aquifers of wide valleys and basins that are also largely feeding from karst outflows. The percentage of karst water in the public supply varies from one country to another, the highest being in Montenegro, where it exceeds 80%. Many large settlements, including six capital cities of this region, base their water supply on tapped karst springs. Most cities along the shores of the Adriatic and Ionian seas, as well as many settlements on the islands, were founded near large springs and their development is the result of these springs' presence. For instance, cities such as Rijeka, Split, Dubrovnik and Kotor became important naval and, later, tourist centres thanks to these large water sources.

The applied technical solutions for karst water tapping were often revolutionary at the time they were created, and represent excellent engineering examples even by today's standards. During the peak of its power, imperial Rome used water mostly from the karst, in the amount of 13 m³/s. Water was supplied through 11 big aqueducts, the largest of which was over 90 km long. Similarly, the source of Peschiera meets about 60% of the overall current water demand of the city of Rome. Regional waterworks from the sources that drain the southern slopes of the Apennine karst lead to Campania (supplying Naples and many other smaller towns) and Puglia (Bari, Taranto and others). Intakes at the sources Kaiserbrunn and Kläffen have reliably supplied the citizens of Vienna with high quality water for almost one and a half centuries, although the distance between them is more than 150 km. Capturing of the sublacustrine spring Bolje Sestre in the Skadar Basin shore ensured a reliable supply of water to the entire Montenegrin coast and intensified its tourism-related and overall economic development.

Six countries (Montenegro, Bosnia and Herzegovina, Albania, Slovenia, Croatia and Austria) are especially distinguished in terms of water-richness as a result of significant distribution of karst terrains and karst aquifers. On the other hand, there are frequent problems with the unstable regime of karstic springs and the vulnerability of karst to any sort of pollution, requiring special attention as well as measures that would help amortise negative anthropogenic impacts and ensure continued use of these precious water resources. Proposed three essential steps towards more rational utilisation and sustainable development of karstic aquifers

* Centre for Karst Hydrogeology, Department of Hydrogeology, Faculty of Mining and Geology, University of Belgrade, Djušina 7, 11000 Belgrade. e-mail: zstev_2000@yahoo.co.uk

are: 1. Further evaluation of karstic water resources, especially the part that can be used for sustainable extraction; 2. Reducing the anthropogenic pressures on aquifer systems; and 3. Systematic monitoring of these resources.

Keywords: aquifers, karst, Southeast Europe, water, resources

INTRODUCTION

Southeast Europe is known worldwide as the “classic karst” terrain where, thanks also to Serbian geomorphologist Jovan Cvijić, a new scientific discipline karstology was born (1895). In the Alpine orogenic belt and its branches Dinarides, Apennines, Carpathians, Balkans, Hellenides and Pindus (also often named as Pind, Pindos, Pindes Mts.) (Fig. 1) the karstified carbonate rocks are either dominant or widely distributed, and karst aquifers represent the main water resource for potable water supply. Among them are six capitals, while some other very large cities with population of over 500,000 also depend on water supply from karst aquifers (Stevanović, 2010; Stevanović & Eftimi, 2010).

However, dealing with karst aquifers and ensuring regular water supply is not an easy task for the engineers. There are two major concerns: one is the unstable regime of karst aquifers, which often results in reduced springs’ discharge during the recession periods that coincide with summer/autumn months, and the high vulnerability to pollution and limited attenuation capacity of the aquifers. Furthermore, increased water demand – especially during summer/autumn seasons along the Adriatic and Ionian coasts – result in additional pressure on the aquifers, and in many cases shortage of water is evident during this critical period.

Another concern is related to the impact of climate changes, threats of the sea level rising, and salt water intrusion along the coastal zones and at many islands that heavily depend on karst aquifers for potable water supply.

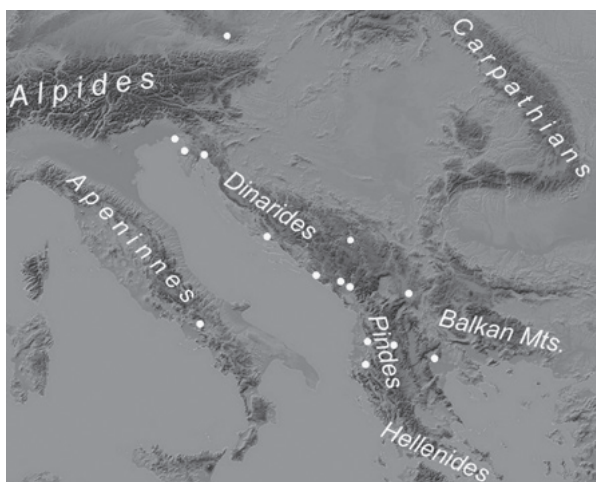


Figure 1. The Alpine orogenic belt and its branches in SE Europe. Dots show locations of some of the most powerful karstic springs

Слика 1. Алпски ороген са гранама – планинским масивима у ЈИ Европи. Тачке приказују локације неких од најснажнијих карстних извора

Water experts and decision makers are also facing challenges in the area of transboundary water management. After the disintegration of former Yugoslavia and the emergence of several newly created countries, many previously domestic aquifers have now become international, requiring a different approach in water management and common understanding of the importance of karst aquifers and equitable share of their waters.

KARST WATERS UTILISATION IN WATER SUPPLY

The tapping of large springs was the traditional method of water supply in the region since the Roman times. For instance, 11 long aqueducts used to deliver more than 13 m³/s of water to ancient Rome from distances ranging from 16 to 91 km (Lombardi & Corazza, 2008). Many of the cities, especially along the Adriatic, Ionian and Aegean coasts, were founded in the vicinity of powerful springs. This is the case with three major cities in Dalmatia, Croatia (Rijeka, Split and Dubrovnik), Kotor in Montenegro, Heraklion in Crete, Greece, and many others.

At present, six capitals in SEE are using karstic waters for drinking purposes (Rome, Vienna, Sarajevo, Tirana, Skopje and Podgorica). The experiences of these capitals and the characteristics of tapped sources are described in greater detail in Stevanović (2010) and Stevanović & Eftimi (2010), while summary data and relevant references are shown in Table 1.

Table 1. Karstic sources of water supply of six capitals of SE Europe
Табела 1. Карстна изворишта која снабдевају шест престоница ЈИ Европе

City / Град	Spring / Извор	Discharge rate / Издашност (m ³ /s)	% of potable water supply / % учешћа у водоснабдевању	Reference / Референца
Rome	Peschiera (Fig. 2)	18–21	60	Boni & Bono, 1984; Petitta, 2009
Vienna	Kaiserbrunn, Kläffer	4.5	95	Drennig 1973, Plan et al., 2010
Sarajevo	Vrelo Bosne	1.4–24	80	Čičić & Skopljak, 2004
Tirana	Selita, Shemria, Buvilla	> 1.5	60	Eftimi, 2010
Podgorica	Mareza	2–10	80	Radulović, 2000
Skopje	Vrelo Rašče	2.5	90	Kekić, 1982

Many other cities and tourist centres along the Adriatic, Ionian and Aegean coasts are also consumers of karstic groundwater (Stevanović & Filipović, 1994; Milanović, 2005; Radulović, 2000; Stevanović & Eftimi, 2010; Fiorillo & Guadagno, 2012; Kallioras & Marinou, 2015). The cities of Southern Italy – Naples, Bari and many others – utilise large springs such as Caposele ($Q_{av.} = 4 \text{ m}^3/\text{s}$), Serino ($Q_{av.} = 2.2 \text{ m}^3/\text{s}$); the largest spring on the northern Italian coast, Timavo, with an average discharge rate of $30 \text{ m}^3/\text{s}$, supplies water to Trieste; Rižana near Koper ($Q_{av.} = 4.3 \text{ m}^3/\text{s}$) is the main source for supplying water to Slovenia's coastal zone; the Žvir group of springs ($0.6\text{--}3.0 \text{ m}^3/\text{s}$) supplies water to Rijeka, the largest Croatian port; while Jadro Spring ($3\text{--}50 \text{ m}^3/\text{s}$) is the main source for the water supply of Split. Ombra Spring is the largest permanent karstic spring in the Southern Adriatic ($Q_{min} = 2.3 \text{ m}^3/\text{s}$), supplying water to the city of Dubrovnik.



Figure 2. Overflow at the Peschiera spring (Velino Basin), tapped to supply the city of Rome

Слика 2. Прелив на врелу Пескијера (слив реке Велино), каптираног за град Рим

Before the new regional water supply of the Montenegrin Coast was completed in 2010, all coastal cities used water from local springs. City of Kotor used water from several springs located around the city walls (Škurda, Gurdić, Tabačina, Vrmac tunnel), Budva shared the waters of Podgorska vrela Sjenokos with Cetinje, while

more than 10 springs and well fields were used to supply potable water to citizens and tourists of the Bar municipality. Nowadays, water supply of the coastal area is ensured from Bolje sestre karstic source (Fig. 3), located some 40 km inland at the Skadar Lake shoreline. For tapping this sublacustrine spring ($Q_{\min} = 2.3 \text{ m}^3/\text{s}$), and to prevent the mixing of fresh karstic groundwater with lake water, a special intake – elliptical coffer dam was constructed (Stevanović et al., 2008; Stevanović, 2010).

Beside Tirana, some other big Albanian cities as Kukeş, Pogradec, Vlora, Berat, Gjakova are also karst waters user (Eftimi, 2010).

In the continental part of the region, in Greece, Romania, Bulgaria and Serbia, there are several large cities that depend on karst aquifers and their discharge regimes. Among them are: Thessaloniki, Craiova, Trgu Jiu, Turnu Severin, Constanza, Gabrovo, Prijepolje, Niš, Bor and Pirot (Stevanović & Filipović, 1994).



Figure 3. Bolje sestre source at the Skadar Lake shoreline, which now supplies the entire Montenegrin Coast

Слика 3. Карстно извориште Боље сестре на ободу Скадарског језера, данас снабдева водом целокупно Црногорско приморје

KARST AQUIFERS DISTRIBUTION AND DEVELOPMENT AT THE COUNTRY LEVEL

SEE is one of the most water-rich regions in the world, but due to its specific water regime and the behaviour of the karst, local population often suffers from water shortages. In the mountains high above the sea level and the erosional base,

groundwater table is often very deep, with no available surface waters. The only way to provide water to the local villagers and their livestock is to build cisterns and specific intakes for collecting rainwater (Fig. 4).



Figure 4. A typical cistern – reservoir for rainwater in the high mountain of Vojnik, between Nikšić and Šavnik (Montenegro)
Слика 4. Типична цистерна – резервоар кишнице на планини Војник, између Никшића и Шавника (Црна Гора)

Considering the above, where is the evidence of the water richness of karst aquifers in SE Europe?

Table 2 shows some statistical data of water budget elements and the availability for 12 countries of SE Europe in which karst terrains and aquifers are widely distributed. Most of these data are available from the FAO – Aquastat database (<http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en>). The presented data mostly refer to the year 2014. Some are missing from the database, and therefore data used for Serbia, Montenegro and North Macedonia came from their current Water Master Plans and some other available references (Prohaska et al., 2000; Radulović, 2000; Hrvačević, 2004).

Additional sources of information on karst aquifers and their waters – shown in Table 3 – were the WOKAM database and the article of Goldscheider et al. (2020). The project World Karst Aquifer Map (WOKAM) was completed in 2017, after five years of work of an international team of experts (Scientific Advisory Board) and many national consultants. Along with the displayed map (https://www.mags-projekt.de/whymap/EN/Maps_Data/Wokam/wokam_node_en.html), the distribution of karst aquifers in each of the European countries was evaluated, and

selected data for SEE region elaborated by Stevanović et al. (2016) were included in Table 3. The assessment of the current contribution of karst water use in the total potable water supply of the SEE countries is the result of the project ‘COST 65’, the article by Hartmann et al. (2014) and of the analysis of global karst water use by Stevanović (2019).

Regarding the average volume of water resulting from precipitation, the leaders are countries of former Yugoslavia from the Dinaric region, plus Austria and Albania (Table 2). These countries, with the exception of Austria, also happen to be the richest in contribution of groundwater to the total internally renewable water resources. Along with them, Italy and Bulgaria also have a contribution of groundwater that is larger than 20%. Countries that impact the withdrawal of water resources the most are Italy and Greece, where each inhabitant uses more than 800 m³ per year.

Data depicting water availability per capita (Table 3) are more illustrative. In an average hydrological year, each inhabitant of Montenegro has 21,395 m³ of water available, but utilises just 1.18% of this volume. In Bosnia and Herzegovina the utilisation rate is even lower, below 1%. Citizens of Croatia and Albania use less than 5% of water that is available to them per capita.

The above figures are closely linked to the distribution of karst terrains, high permeability of karst aquifer systems, and highly effective infiltration of rainfall into the ground. On one side, there are countries with less than 20% of territory covered by karst rocks, where also generally less than 20% of population consumes karst water (Romania, Serbia, North Macedonia). In contrast, even though more than 30% of the territory of Bulgaria is karst, less than 10% of population uses karst water. Bulgaria is also the only country in SEE where the percentage of karst territory is significantly higher than the percentage of population that uses karst water for drinking purposes (Fig. 5). On the other side are the countries with wide distribution of karst and intensive water balance that enable their citizens to have large contribution of karst waters in their potable water supply. The leader of this group is once again Montenegro, where 85% of the population is drinking karst groundwater, while more than 50% of the citizens of Bosnia and Herzegovina, Albania, Slovenia and Austria also meet their daily demands using this water resource. Figure 5 shows good correlation between the distribution of karst and utilisation of karst waters at the country level.

Finally, Table 3 shows six countries that have more than 25% of their territories covered by karst, but utilise less than 10% of their internal renewable water resources. In these countries (Montenegro, Bosnia and Herzegovina, Albania, Slovenia, Croatia and Austria), each citizen has more than 5,000 m³ of water available annually. This amount is ten times higher than the level which in certain UN documents is indicated as limit for “water stressed countries”. It is clear that the Dinaric region of “classic karst” – further extended to the Alps (Austria) and the “Albanian Alps” – is by far the richest in karst water resources.

Table 2. Statistical data on water resources availability and consumption in countries of SE Europe
 Табела 2. Статистички подаци о расположивости и коришћењу водних ресурса у земљама ЈИ Европе

Country / Држава; data for the year 2014 (or for the year in brackets) / подаци за 2014 (или за годину у заграда)	Long-term average annual precipitation / Средње годишње суме падавина (P)	Long-term average annual precipitation volume / Ср. годишња запремина суме падавина (P)	Ground-water produced internally / Домицилне подземне воде	Total domestic renewable water res. (IRWR)/ Ук. обновљиви домицилни водни ресурси	% of ground- water in IRWR / % учешћа подз. вода у обновљивим резервама	Total water withdrawal (for the year) / Укупна експлоатација подземних вода (за годину)	Population in 1.000.000 / Становници у милионима	Total water withdrawal per capita / Укупне експлоатационе количине воде по становнику
	(mm/year)	(10 ⁹ m ³ /year)	(10 ⁶ m ³ /year)	(10 ⁶ m ³ /year)		(10 ⁹ m ³ /year)		(m ³ /inhab/year)
Austria	1 110	93.11	6	55	8.3	3.492(2010)	8.5	413 (2010)
Albania	1 485	42.69	6.2	26.9	23	1.311(2006)	3.6	435.4 (2006)
Bosnia & Herzegovina	1 028	52.64	11.57	35.5	32.6	0.3279(2013)	3.8	86.06 (2013)
Bulgaria	608	67.49	6.4	21	30	5.629(2015)	7.3	787.3 (2015)
Croatia	1 113	62.98	11	37.7	29.2	0.6338(2013)	4.3	149.5 (2013)
Greece	652	86.04	10.3	58	17.8	9.63(2007)	10.8	865.2 (2007)
Italy	832	250.7	43	182.5	23.5	53.75(2008)	60	899.8 (2008)
Montenegro*	1 805	24.93	8.45	13.6	62	0.1609(2010)	0.62	257.9 (2010)
Serbia**	734	64.85	2.7	16	17	4.15(2013)	9	468.9 (2013)
Slovenia	1 162	23.55	13.5	18.67	72	1.156(2013)	2.1	559 (2013)
Romania	637	151.9	8.38	42.38	19.8	6.418(2013)	20.1	328.9 (2013)
North Macedonia**	619	15.91	<1	5.4	18.5	0.5512(2007)	2.1	268.7E(2007)

* VOS CG, 2001; from Radulović, 2000; Hrvacević, 2004; ** FAO; upgraded by Prohaska et al., 2000; Stevanović et al., 2015.

Table 3. Statistical data on karst land surface and the use of karstic water resources in the countries of SE Europe
Табела 3. Статистички подаци о распрострањењу карстних терена и коришћењу карстних водних ресурса у земљама ЈИ Европе

Country / Држава	Total available IRWR per capita / Укупно расположиви водни ресурси по становнику (m ³ /inhab/year)	% of total water use vs. IRWR / % коришћења према расположивим ресурсима	1000 km ² of karst terrains / 1000 km ² карстних терена у држави (after WOKAM)	% of karst vs. total surface of the country / % учешћа карста у територији државе (after WOKAM)	Estimated % of karst water use vs. total / Оцена % коришћења карстних водних ресурса у укупно искоришћеним водама	Countries with >25% of karst territory, <10% of utilized IRWR, and available >5000m ³ /inhab/year / Државе са >25% карста, <10% коришћ. укупно расположивих водних ресурса и расположивих >5000 m ³ /становник/год.
Austria	6470	6.3	20.9	25	51	Austria
Albania	7472	4.9	9.8	34.3	70	Albania
Bosnia & Herzegovina	9342	0.92	31.2	60.5	56	Bosnia & Herzegovina
Bulgaria	2876	26.8	30.1	27.1	<10	
Croatia	8767	1.68	22.8	40.9	38	Croatia
Greece	5370	16.7	35.3	27.1	35	
Italy	3042	29.5	57.4	19.1	40	
Montenegro	21935	1.18	11	80.1	85	Montenegro
Serbia	1777	25.9	15.8	17.9	18	
Slovenia	8890	6.2	10.1	49.5	52	Slovenia
Romania	2108	15.1	5.5	2.3	<10	
North Macedonia	2571	10.2	3.2	12.4	40	

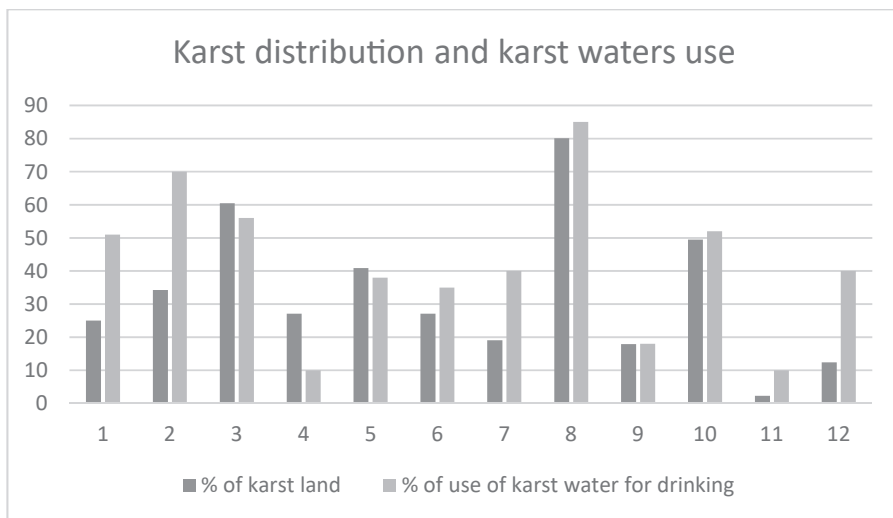


Figure 5. Relation between the percentage of area covered by karst and the actual karst water use for water supply in the countries of SE Europe (1 – Austria, 2 – Albania, 3 – Bosnia and Herzegovina, 4 – Bulgaria, 5 – Croatia, 6 – Greece, 7 – Italy, 8 – Montenegro, 9 – Serbia, 10 – Slovenia, 11 – Romania, 12 – North Macedonia)

Слика 5. Однос учешћа покривености карстом и коришћења карстних водних ресурса (у %) у јавном водоснабдевању становништва у земљама ЈИ Европе (1 – Аустрија, 2 – Албанија, 3 – Босна и Херцеговина, 4 – Бугарска, 5 – Хрватска, 6 – Грчка, 7 – Италија, 8 – Црна Гора, 9 – Србија, 10 – Словенија, 11 – Румунија, 12 – Северна Македонија)

The above statement was confirmed by the results of two important completed projects.

In the WOKAM project, the author of this paper was responsible for the evaluation of data for 47 countries, including Alpine karstic systems. The preliminary list that was created for the WOKAM database consists of 124 major springs and 52 caves located in these countries, at least 53 of which were proposed to be shown on the printed map (Stevanović et al., 2016).

By far, the largest number of springs shown on the WOKAM map is from Dinaric karst (Fig. 6). For instance, four countries which were part of former Yugoslavia are the leaders concerning the density of springs: the distribution of large karstic springs that meet the discharge criterion vs. territory covered by karst in Croatia, Slovenia, Montenegro and Bosnia and Herzegovina is equal to or larger than 1 spring/2,000 km². A considerable number of springs is also characteristic of other countries that contribute in part to the Dinaric system: in the Albanian part of the Dinarides, there are 2 large springs (Eftimi, 2010), in the Dinarides of western Serbia – 4, in North Macedonia – 4. In the Southern extensions of Alpides, Pindus and Hellenides, four Albanian and two Greek springs are included in the WOKAM database. However, additional restriction has been applied due to the scale of the map and the criteria

of global proportion, so the final WOKAM map displays 30 springs (BGR website – https://www.mags-projekt.de/whymap/EN/Maps_Data/Wokam/wokam_node_en.html). This is 58% of all springs shown on the map for the entire Europe, or 18.5% of all the world's springs shown. Considering that SE Europe represents just 0.86% of the entire ice-free land of the Earth, the level of contribution of its water resources, especially karst aquifers, to the global water budget is quite clear.

Within the DIKTAS project (Dinaric Karst Transboundary Aquifer System), the evaluation of water budget and actual water use comprise eight main transboundary karst aquifers (TBA): Una (Fig. 7), Krka, Cetina, Neretva, Trebišnjica (all shared by Croatia and Bosnia and Herzegovina), Bilećko Lake, Piva (B&H and Montenegro) and Cijevna/Cemi (Montenegro and Albania). The analysis indicates that water extraction is still far below the aquifer's replenishment potential, and there is no evidence of significant over-exploitation in the studied TBAs (Stevanović et al., 2016). For instance, in the case of Cetina and Neretva TBAs, the average extraction of groundwater is ten times lower than the total minimal discharge of the local springs (dynamic reserves). However, shortage of water is evident locally during summer and early autumn months, coinciding with increased demands caused by the tourist season.



Figure 6. Dense distribution of karstic springs in the Dinaric part of the SE Europe on one of draft WOKAM maps (from Stevanović et al., 2016)

Слика 6. Локације карстних извора у Динарском карсту ЈИ Европе на једној од радних карата WOKAM пројекта

Similarly, the analysis of actual water use versus the total available dynamic groundwater reserves for tested karst aquifers, conducted on the territory of the Federation of Bosnia and Herzegovina in the Sava River basin, confirms that with most of the aquifers just a small portion of the available waters is actually used (Stevanović et al., 2015). For instance, in karst groundwater body “Upper Una” – only 10%, and in “Upper Sana” – less than 5% of renewable (dynamic) reserves is currently utilised.



Figure. 7. Klokot spring, which supplies the city of Bihać, is the main source of the Una transboundary karst aquifer (Croatia – Bosnia & Herzegovina)
Слика 7. Клокот, карстно врело које снабдева водом Бихаћ, највеће је извориште међуграничне карстне издани Уна (Хрватска – БиХ)

CONCLUSIONS

The karst aquifers of the Alpine orogenic belt and its branches of SE Europe are the essential water resource for potable water supply. Due to wide karst rocks distribution, intensive water balance and the effective infiltration of rainfall, this region is among the richest in the world concerning total water resources and their availability to consumers. The six countries of SE Europe, namely Montenegro, Bosnia and Herzegovina, Albania, Slovenia, Croatia and Austria, are actual leaders when it comes to water resources availability. In all of them more than 25% of territory is covered by karst, less than 10% of their internal renewable water resources is utilised, and each citizen has more than 5,000 m³ available annually.

Although they are faced with many challenges in ensuring a stable water supply and preventing the deterioration of these aquifers from over-extraction during critical summer-autumn months and improper local waste management, water managers and hydrogeologists estimate that, in most of the region, karstic aquifers will certainly remain the main source of water supply for a long time. However, there are still many steps that must be taken towards more rational utilisation and sustainable development of karstic aquifers. The three essential steps are:

1. Further evaluation of karstic water resources, especially the part that can be used for sustainable extraction;
2. Reducing the anthropogenic pressures on aquifer systems; and
3. Systematic monitoring of these resources.

REFERENCES / ЛИТЕРАТУРА

- Boni C., Bono P., 1984: Essai de bilan hydrogéologique dans une région karstique de l'Italie centrale. In: Burger A. & Dubertret L. (eds.): Hydrogeology of karstic terrains: Case histories. Intern. Contrib. to Hydrogeology, Vol 1, IAH, Heise, pp. 27–31.
- COST 65 (Cooperation in Science and Technology), 1995: Hydrogeological aspects of groundwater protection in karstic areas, Final report (COST action 65), Brussels, Luxemburg, p. 446.
- Cvijić J., 1895: Karst, a geographic monograph (Serbian version of „Das Karstphänomen“, 1893). Reprinted In: Stevanović Z. & Mijatović B. (eds.): Cvijić and karst / Cvijić et karst, Spec. ed. of Serb. Acad. Sci. and Arts (2005), Belgrade, pp. 57–146.
- Čičić S., Skopljak F., 2004: Geological and hydrogeological conditions of Vrelo Bosne catchment area (in Bosnian). Voda, Sarajevo, 37: 4–10.
- Drennig A., 1973: Die I. Wiener Hochquellenwasserleitung. Magistrat der Stadt Wien, Abteilung 31 – Wasserwerke, Wien, p. 303.
- Eftimi R., 2010: Hydrogeological characteristics of Albania, AQUA-mundi, AM01012, vol. 1: 79–92.

- FAO, 2016: AQUASTAT website. Food and Agriculture Organization of the United Nations (FAO). www.fao.org/nr/aquastat/water_use/index.stm Website accessed on [2016/10/21; 2017/11/17].
- Fiorillo F., Guadagno F. M., 2012: Long karst spring discharge time series and drought occurrences in southern Italy. *Environ. Earth Sci.*, 65(8): 2273–2283.
- Goldscheider N., Chen Z., Auler A. S., Bakalowicz M., Broda S., Drew D., Hartmann J., Jiang G., Moosdorf N., Stevanović Z., Veni G., 2020: Global distribution of carbonate rocks and karst water resources, *Hydrogeology Journal*, 28(5): 1661–1677.
- Hartmann A., Goldscheider N., Wagener T., Lange J., Weiler M., 2014: Karst water resources in a changing world: Review of hydrological modeling approaches, *Review of Geophysics*, v. 52, no. 3: 218–242.
- Hrvačević S., 2004: Resursi površinskih voda Crne Gore. Elektroprivreda CG A.D., Nikšić, p. 331.
- Kallioras A., Marinos P., 2015: Water resources assessment and management of karst aquifer systems in Greece. *Environ. Earth Sci.*, Them. issue – Fiorillo F. & Stevanović Z. (eds.): *Mediterranean Karst Hydrogeology*, 74: 83–100.
- Kekić A., 1982: About groundwater in karstic terrains (in Serbian). *Proceedings of VII Yugoslav. Symp. of hydrogeol. and eng. geol.* vol. 1, Novi Sad, pp. 123–133.
- Lombardi L., Corazza A., 2008: L'acqua e la città in epoca antica. In: *La Geologia di Roma, dal centro storico alla periferia, Part I, Memoire Serv. Geol. d'Italia, Vol LXXX, S.E.L.C.A, Firenze*, pp. 189–219.
- Milanović P., 2005: Water potential in southeastern Dinarides. In: Stevanović, Z. & Milanović, P. (eds.): *Water resources and environmental problems in karst, Proceedings of IAH International conference KARST 2005, Belgrade–Kotor, Fac. Min. & Geol., Belgrade*, pp. 249–257.
- Petitta M., 2009: Hydrogeology of the middle valley of the Velino River and of the S. Vittorino Plain (Rieti, Central Italy). *Italian Journal of Engineering Geology and Environment*, 1: 157–181.
- Plan L., Kushnig G., Stadler H., 2010: Kläffer spring – The major spring of the Vienna water supply. In: Kresic N. & Stevanović Z. (eds.): *Groundwater Hydrology of Springs: Engineering, Theory, Management, and Sustainability, Elsevier Inc.*, pp. 411–427.
- Prohaska S., Ristić V., Srna P., Petković T., Marčetić I., 2000: Water Resources of Serbia. In: Stevanović Z. & Polomčić D. (eds.): *Hydrogeological Research of Lithosphere of Serbia, Inst. Hydrogeol. Fac. Min. & Geol. Belgrade*, pp. 5–11. (Reprinted from: *Proceedings of the XVIII Conference of Danube countries "Hydrological Forecasting and Hydrological Bases for Water Management"*, Graz).
- Radulović M., 2000: Hidrogeologija karsta Crne Gore. Pos. izd. Rep. Zavoda za geol. istraž. CG, vol. XVIII, Podgorica, p. 271.
- Stevanović Z., Filipović B. (eds), 1994: Ground waters in carbonate rocks of the Carpathian-Balkan mountain range. *Spec. ed. of CBGA, Allston, Jersey*, p. 237.
- Stevanović Z., Radulović M., Puri S., Radulović MM., 2008: Karstno izvorište „Bolje sestre“ – optimalno rešenje regionalnog vodosnabdevanja Crnogorskog primorja, *Zbornik Odbora za kras i speleologiju SANU, Beograd*, IX: 33–64.

- Stevanović Z., 2010: Major springs of southeastern Europe and their utilization. In: Kresic N. & Stevanović Z. (eds.): Groundwater Hydrology of Springs: Engineering, Theory, Management, and Sustainability, Elsevier Inc., pp. 389–410.
- Stevanović Z., Eftimi R., 2010: Karstic sources of water supply for large consumers in southeastern Europe – sustainability, disputes and advantages, *Geologica Croatica*, 63/2: 179–186.
- Stevanović Z., 2015: Tapping of Karst Groundwater. In: Stevanović Z. (ed.): Karst Aquifers – Characterization and Engineering, Series: Professional Practice in Earth Science. Springer Intern. Publ. Switzerland, pp. 299–334.
- Stevanović Z., Marinović V., Merdan S., Skopljak F., Jolović B., 2015: Koncept izrade hidrogeoloških podloga za planove upravljanja rečnim slivovima, Zbornik radova I Kongresa geologa BiH sa međunarodnim učešćem, Udr. geologa BiH, Tuzla, pp. 150–151.
- Stevanović Z., Goldscheider N., Chen Z. and the WOKAM Team, 2016: WOKAM – The world karst aquifer mapping project, examples from South East Europe, Near and Middle East and Eastern Africa, In: Stevanović Z., Krešić N. and Kukurić N. (eds.): Karst Without Boundaries, CRC Press/Balkema, EH Leiden; Taylor & Francis Group, London, pp. 39–51.
- Stevanović Z., 2019: Karst waters in potable water supply: a global scale overview. *Environmental Earth Science*. Springer, 78: 662; <https://doi.org/10.1007/s12665-019-8670-9>
- VOS CG, 2001: Vodoprivredna osnova Crne Gore, Inst. za vodoprivredu „Jaroslav Černi“, Beograd.
- WOKAM map displayed at the BGR web site: https://www.mags-projekt.de/whymap/EN/Maps_Data/Wokam/wokam_node_en.html

Зоран Стевановић

КАРСТНЕ ИЗДАНИ ЈУГОИСТОЧНЕ ЕВРОПЕ – ЕСЕНЦИЈАЛНИ И БОГАТИ РЕСУРС ВОДЕ ЗА ПИЋЕ

Резиме

Подручје ЈИ Европе обилује подземним водама акумулираним у карстним изданима планинских масива Алпског орогена и интергрануларним изданима широких долина и басена формираних у међупланинским депресијама. И ове воде нижих предела у великој мери су генерисане подземним дотицајем из карста. Процент учешћа вода карстних издани у јавном снабдевању варира од државе до државе; највећи је у Црној Гори, у којој прелази 80%. Многа велика насеља, укључујући и 6 главних градова ове области, своје водоснабдевање базирају на подземним водама каптираних карстних извора. Већина градова дуж обале Јадранског, Јонског и Егејског мора, као и насеља на острвима, лоцирани су и развијали су се поред карстних извора. Од издашности,

стабилности режима и изолованости ових извора од морских вода, зависио је и укупни развој ових градова. Тако су управо захваљујући јаким или бројним изворима Ријека, Сплит, Дубровник, Котор могли постати важни поморски и трговачки центри.

Примењена техничка решења захвата вода карстних издани била су често револуционарна за време у коме су настајала, а нека и данас могу да послуже као изванредни инжењерски примери. Империјални Рим у време врхунца своје моћи користио је воде претежно из карста, и то у количини од 13 м³/с. Вода је допремана преко 11 изграђених аквадукта, од којих је највећи имао дужину од преко 90 км. Слично и данас, извор Пескијера задовољава са око 60% укупне потребе у води града Рима. Регионални водоводи који полазе од извора који дренирају јужне обронке Апенинског карста спроводе воде до Кампање (за Напуљ и бројне мање градове) и Пуље (Бари, Таранто и други). Каптаже на изворима Кајзербрун и Клафен већ скоро читав један и по век поуздано и водом високог квалитета снабдевају грађане Беча иако су од њих удаљени преко 150 км. Каптирање вруље Боље сестре у Скадарском басену данас омогућује поуздано снабдевање водом целокупног Црногорског приморја и интензивирање његовог туристичког и укупног привредног развоја.

Шест држава се посебно издваја у погледу водообилности, што је резултат знатног распрострањења карстних терена и водом богатих карстних издани. У њима карст покрива више од 25% територије, користи се мање од 10% укупно расположивих водних ресурса и расположиво је на годишњем нивоу више од 5000 м³ по становнику, што је више од 10 пута од уобичајене норме за проглашење државе да се налази под „водним стресом“. То су Црна Гора, Босна и Херцеговина, Албанија, Словенија, Хрватска и Аустрија. С друге стране, постоје проблеми нестабилног режима и рањивости карстне издани који захтевају посебну пажњу и потребу за применом мера које би помогле да се амортизују негативни антропогени утицаји на простору карста и обезбеди даље одрживо коришћење расположивих водних ресурса. Предложене три основне мере обухватају: 1. даљу, детаљнију оцену водних ресурса у карсту, посебно дела расположивих вода за одрживо коришћење; 2. смањење антропогених утицаја на карстне издани; 3. систематски мониторинг водних ресурса.

Кључне речи: издани, карс, југоисточна Европа, вода, ресурси