NATURA SLOVENIAE 20(2): 61-64
»SOS *Proteus*« – SCIENTIFIC NOTE
Prejeto / Received: 23. 10. 2018
Sprejeto / Accepted: 6. 12. 2018

Identification of cave pollution in the Kras Plateau, Slovenia

Prepoznavanje onesnaženosti jam na planoti Kras, Slovenija

Jure TIČAR, Daniela RIBEIRO, Geografski inštitut Antona Melika ZRC SAZU, Gosposka ulica 13, SI-1000 Ljubljana;
E-mails: jure.ticar@zrc-sazu.si, daniela.ribeiro@zrc-sazu.si

The biggest issue facing European hydrogeologists is the need to protect the quality and quantity of groundwater resources (Zwahlen 2003). Cave pollution (the term is here used as: caves that are filled with waste) is among the drivers contributing to the pollution and degradation of karst aquifers. Nonetheless, the extent of the problem is neither well described nor systematically monitored at the national level (Prelovšek 2011a, 2011b). In Europe, karst covers around 1.4 million km^2 or 13.8% of the land surface (Chen et al. 2017), and provides an important share of drinking water, e.g. in Austria the share is more than 50%, in Croatia more than 35% and in Belgium more than 30% (COST 1995). In Slovenia, karst landscapes are recognizable and important features at the national level (Habič 1992, Mihevc 1999, Gams 2004, Zupan Hajna 2004, Ribeiro 2017). These landscapes cover approximately 8,800 km^2 or 44% of the country's surface, while the karst springs provide about 43% of drinking water (Lah 1998).

In the past, several attempts were undertaken to evaluate the extent of cave pollution in Slovenia (Prelovšek 2011b). They took place in the Municipality of Novo mesto (Hudoklin 2002), the catchment of the Krka River Spring (Čekada 2011), the karst areas around Celje Plain (Hribernik et al. 2010) and in the Kras Plateau (Prelovšek 2013). In some areas, the pollution can be present in up to 46% of the investigated caves, whereas the estimation of cave pollution for Slovenia is around 20% of the total number of caves (Čekada 2015). Recently, an overview of cave pollution has been made for Bela krajina (Ribeiro & Tičar 2017), where cave pollution affected around 19% of the investigated caves and presents a potential threat to the black olm (*Proteus anguinus parkelj*) (Sket et al. 2003) as well as other subterranean water organisms. At the European level, different remediation projects have been established by speleological associations, caving clubs, municipalities or research institutions, such as the EU project Life Kočevsko in Slovenia (Prelovšek 2015), the project »Clean underground« in Croatia (Novak & Tutiš 2017) and the project »Cleaning up the darkness – Puliamo il Buio« in Italy (Didonna et al. 2018). In order to systematize and prioritize the remediation of karst underground in Slovenia, the evaluation of cave pollution at the national level is essential.

The main objectives of the present study are the following: 1) to identify the level of cave pollution in the Kras Plateau, 2) to compare the results of this study with results of Prelovšek (2013) done in the same geographical area, and 3) to compare the results to the study done in the karst region of Bela krajina (Ribeiro & Tičar 2017).

The Kras Plateau stretches between the Gulf of Trieste, Soča Plain, Vipava Valley and Brkini Hills (Gams 2004) and covers in Slovenia an area of 429 km^2 (Perko 1998). It consists of the Cretaceous and Paleogene Carbonates and has a distinguished flat surface at an elevation of around 300 m a.s.l. with numerous dolines, collapse dolines and caves (Gams 2004). Due to its highly karstified surface, the surface watercourses are absent and the precipitation percolates directly through the karst vadose zone into the underground aquifer. In addition, the underground aquifer is fed by waters of the Reka River which sink in the caves Škocjanske jame. The inlet from the Soča and Vipava Rivers eventually outflows from the Kras Plateau at the springs of the Timavo (Italian name for the Reka River) at Devin, Gulf of Trieste (Doctor 2008). In the first half of the 19th century, exploration of caves in the Kras Plateau gained special attention due to the exploration of caves for water supply of the city of Trieste (Mihevc et al. 2016).

According to the national Cave Registry, 1,077 karst caves have been registered in the Kras Plateau by the end of 2017 (Cave Registry 2018). The cave density is around 2.5 caves/km^2, and the area is considered as one of the hot-spots regarding karst caves concentration in Slovenia (Mihevc et al. 2016, Tičar et al. 2018). Although caves are distributed all over the Kras Plateau, there is a high density of caves between

Škocjanske jame and Sežana and south from Kostanjevica na Krasu. In total, more than 78 km of cave passages have been discovered so far. The average length of the caves is around 73 m and the average depth is 26 m. There are six caves with more than 1 km of passages (the longest being Kačna jama with 15.2 km), and eight caves with 250 m or more vertical drop (the deepest being Jama Sežanske reke with 394 m (Cave Registry 2018). All the deepest caves in the area reach the underground flow of the Reka River.

Data for this study was obtained from the Cave Registry (2018), while data from Prelovšek (2013) were also obtained from field verifications. We gathered the following data: state of the cave, type of waste encountered inside the cave, usage of the cave, as well as other metric data regarding the morphology of the cave. Since 15 registered caves in the Kras Plateau have no information on cave pollution, only 1,062 caves were included in our analyses.

The results show that 817 caves out of 1,062 are without detectable (not seen with the naked eye) pollution (representing 77%) and 245 caves are polluted (representing 23%). Regarding the amount of waste (measured in m^3), 98 caves are considered to be and are labelled as low polluted (0.1–0.9 m^3), 81 are medium polluted (1.0–4.9 m^3) and 66 are highly polluted (more than 5.0 m^3). Considering the physical state of the caves, 198 (19 %) have been damaged. Different types of physical damage can be present in the same cave and refer to artificial widening of passages (135 caves), broken speleothems (26 caves), paintings on walls or on speleothems (26 caves), repositioning of sediments (47 caves), etc.

In most cases, the waste structure was hard to identify from the observation of cave registers. We determined that the greatest part of the waste belongs to the category of organic waste (65%), followed by communal waste (67%) and finally construction waste (25%). It's important to note that 51 polluted caves (21% of polluted caves) contain dangerous waste (e.g. pesticides, dumped motor oils), from which 37 caves (15% of polluted caves) contain explosive remains from WW I or II. Besides, 9 caves are polluted due to a leakage of polluted wastewater and 14 caves contain human remains.

Considering the use of caves, their past uses were quite diverse. 250 caves out of 1,062 were used as landfill sites, 127 as military shelters, 114 as important caves for research purposes, 14 as burial sites, 7 for the acquisition of raw materials, etc.

As part of this study, we also related the size and type of cave entrance to the state of the cave (clean or polluted). The average size of the cave entrance is 21.7 m^2. Results show that clean caves tend to have smaller entrances (18.4 m^2) than polluted caves (32.5 m^2), however, this difference is not statistically significant. The size of the entrances for the low polluted caves is 9.3 m^2, for medium polluted caves 32.5 m^2, and for highly polluted caves 56.3 m^2.

In order to compare the results from this study to the results from Prelovšek (2013), we used 99 caves (the same caves in both studies) and categorized them according to clean, low polluted, medium polluted and high polluted caves (see Tab. 1).

Table 1. Comparison of results on cave pollution in 99 caves from this study and Prelovšek (2013).
Tabela 1. Primerjava rezultatov raziskave z rezultati Prelovšek (2013).

Variable	Category	Prelovšek (2013)	This study
State of the caves [number of caves]	Clean	64	64
	Polluted	25	32
	Destroyed	5	0
	No data	5	3
Level of pollution [number of caves]	Low polluted	7	10
	Medium polluted	7	10
	High polluted	9	12
	Unspecified level of pollution	2	0
Amount of waste in polluted caves [m^3]	Cumulative amount of waste	386.4	727.6
	Average amount of waste per polluted cave	15.4	22.7

The results from the comparison between cave pollution in the Kras Plateau and in Bela krajina (Ribeiro & Tičar 2017) can be seen in Tab. 2.

Table 2. Comparison between cave pollution in the Kras Plateau and in Bela krajina (Ribeiro & Tičar 2017).
Tabela 2. Primerjava rezultatov raziskave onesnaženosti jam na Krasu in v Beli krajini (Ribeiro & Tičar 2017).

Variable	Category	Ribeiro & Tičar (2017)	This study
State of the caves [% of caves]	Clean	81	77
	Polluted	18	23
	Destroyed	1	0
Level of pollution [% of caves]	Low polluted	47	40
	Medium polluted	16	33
	High polluted	37	27
Amount of waste in polluted caves [m^3]	Cumulative amount of waste	974.2	2,385.4
	Average amount of waste per polluted cave	8.3	9.7

To conclude, this study shows the extent of cave pollution in the Kras Plateau and exposes different factors affecting the caves in the area. Due to the past military activities in the study area, explosive remnants of war can be detected in karst caves. Comparison between our results and Prelovšek (2013) showed similar outcomes. The biggest difference between both studies regards the amount of waste within caves. Since our data were based on Cave Registry (2018) without further field observations, the results suggest an overestimation of the amount of waste in caves comparing to Prelovšek (2013). This finding points out the importance of field observations in addition to the data acquired from the archives. The comparison among regions (Kras Plateau and Bela krajina) showed that the share of polluted caves and amount of waste are higher in the Kras Plateau than in Bela krajina (Tab. 2).

Here we highlight one aspect of cave pollution, directly connected with waste disposal. However, there are other critical drivers of groundwater pollution in karst areas, such as wastewater treatment, population density, land use, and transport infrastructure that were not the scope of this study.

References

Cave Registry (2018): Registry of Slovenian Caves. Karst Research Institute ZRC SAZU, Postojna.

Chen Z., Auler A.-S., Bakalowicz M., Drew D., Griger F., Hartmann J., Jiang G., Moosdorf N., Richts A., Stevanović Z, Veni G., Goldscheider N. (2017): The World karst aquifer mapping project: concept, mapping procedure and map of Europe. Hydrogeol. J. 25: 771-785.

COST (1995): Hydrogeological aspects of groundwater protection in karstic areas: Final report. European Commission, Brussels, 446 pp. https://cordis.europa.eu/publication/rcn/199511660_es.html

Doctor D.-H. (2008): Hydrologic connections and dynamics of water movement in the Classical Karst (Kras) aquifer: evidence from frequent chemical and stable isotope sampling. Acta Carsol. 37(1): 101-123.

Čekada M. (2011): Terenski pregled jam v hidrogeološkem zaledju izvira Krke. Jamar 4(2): 32-34.

Čekada M. (2015): Kraljestvo smeti – več kot 2000 onesnaženih jam v Sloveniji. Jamar 7: 53.

Didonna F., Maurano F., Pani D. (2018): Cleaning up the darkness – »Puliamo il buio (PiB)«, over a decade of cave depollution activities in Italy 2005-2017. In: Mattes J., Plan L., Christian E. (Eds.), Proceedings of the 12th EuroSpeleo Forum, Verein für Höhlenkunde Ebensee, Ebensee, p. 36.

Gams I. (2004): Kras v Sloveniji v prostoru in času, 2. edition. Založba ZRC, Ljubljana, 515 pp.

Habič P. (1992): Kras and karst in Slovenia. In: Černe A. (Ed.), Slovenia, geographic aspects of a new independent European nation, The Association of the Geographical Societies of Slovenia, Ljubljana, pp. 31-39.

Hribernik M., Bračič R., Čekada M., Novak T., Ravljen J. (2010): Varstvo kraških jam in virov pitne vode: Velenjsko in Konjiško hribovje, Dobroveljska planota, Ložniško in Hudinjsko gričevje ter Savinjska ravan. Koroško-šaleški jamarski klub Speleos – Siga, Velenje, 65 pp.

Hudoklin A. (2002): Onesnaženost jam v Mestni občini Novo mesto. In: Hudoklin A. (Ed.), Dolenjski kras 4, Jamarski klub Novo mesto, Novo mesto, pp. 69-76.

Lah A. (1998): Voda – vodovje: poglavitni življenjski vir narave in gospodarstva. Svet za varstvo okolja Republike Slovenije, Ljubljana, 63 pp.

Mihevc A. (1999): Morfologija krasa. In: Čuliberg M., Kranjc A. (Eds.), Kras: pokrajina, življenje, ljudje, Založba ZRC, Ljubljana, pp. 41-47.

Mihevc A., Gabrovšek F., Knez M., Kozel P., Mulec J., Otoničar B., Petrič M., Pipan T., Prelovšek M., Slabe T., Šebela S., Zupan Hajna N. (2016): Karst in Slovenia. Boletín Geológico y Minero 127(1): 79-97.

Novak R., Tutiš S. (2017): »Čisto podzemlje«. In: Lučić N., Janjanin Ž., Paar D., Gregov A. (Eds.), Zbornik sažetaka – Skup speleologa Hrvatske, Čilipi 2017, Hrvatsko planinarsko društvo Snježnica, Dubrovnik, p. 47.

Perko D. (1998): The regionalization of Slovenia. Acta Geogr. Slov. 38: 11-57.

Prelovšek M. (2011a): Vulnerability, pressures and protection of karst caves. In: Prelovšek M., Zupan Hajna N. (Eds.), Pressures and protection of the underground karst – cases from Slovenia and Croatia, Karst Research Institute ZRC SAZU, Postojna, pp. 11-17.

Prelovšek M. (2011b): Pollution and cleanup of karst caves in Slovenia. In: Prelovšek M., Zupan Hajna N. (Eds.), Pressures and protection of the underground karst – cases from Slovenia and Croatia, Karst Research Institute ZRC SAZU, Postojna, pp. 101-111.

Prelovšek M. (2013): Projekt 99, popis onesnaženosti jam na Krasu (poročilo). ZRC SAZU in Jamarska zveza Slovenije, Ljubljana, 16 pp.

Prelovšek M. (2015): Zaključno poročilo o popisu onesnaženosti 90 jam na Kočevskem (poročilo). Inštitut za raziskovanje krasa ZRC SAZU in Jamarski klub Novo mesto, Postojna, 20 pp.

Ribeiro D. (2017): Impact of landscape features on land use and regional development in karst areas: a case study of Bela krajina. Doctoral thesis, University of Ljubljana, Ljubljana, 281 pp.

Ribeiro D., Tičar J. (2017): The problematics of cave pollution in Bela krajina. Nat. Slo. 19(1): 43-45.

Sket B., Gogala M., Kuštor V. (2003): Živalstvo Slovenije. Tehniška založba Slovenije, Ljubljana, 664 pp.

Tičar J., Perko D., Volk Bahun M. (2018): Geodediščina in pokrajinska raznolikost Slovenije. In: Ciglič R., Geršič M., Perko D., Zorn M. (Eds.), Pokrajina v visoki ločljivosti, Založba ZRC, Ljubljana, pp. 57-74.

Zupan Hajna N. (2004): Karst in Slovenia. In: Orožen Adamič M. (Ed.), Slovenia: a geographical overview, Založba ZRC, Ljubljana, pp. 39-44.

Zwahlen F. (2003): Vulnerability and risk mapping for the protection of carbonate (karst) aquifers, scope – goals – results. European Commission, COST action 620, Directorate-General Science, Research and Development, Luxembourg, 39 pp. http://www.bgr.bund.de/EN/Themen/Wasser/Projekte/abgeschlossen/F+E/Cost620/cost620_fb_02_pdf.pdf?__blob=publicationFile&v=1