NATURA SLOVENIAE 18(1): 35-42
»SOS PROTEUS« – SHORT COMMUNICATION

Prejeto / Received: 12.12.2015
Sprejeto / Accepted: 30.6.2016

Groundwater dependent ecosystems – groundwater status indicators

Kim MEZGA, Mitja JANŽA, Joerg PRESTOR, Katja KOREN, Dejan ŠRAM

Geological Survey of Slovenia, Dimičeva ulica 14, SI-1000 Ljubljana, Slovenia; E-mails: kim.mezga@geo-zs.si, mitja.janza@geo-zs.si, joerg.prestor@geo-zs.si, katja.koren@geo-zs.si, dejan.sram@geo-zs.si

Abstract. Within the framework of »Water Management Plan for the Danube River Basin and the Adriatic Sea 2015-2021 (NUV II)«, a study on the groundwater status of karst aquifers which are habitats of groundwater dependent ecosystems (GDEs) was carried out. Among them are the habitats of olms (*Proteus anguinus*), the endemic species of Dinaric karst. These habitats have been included in the Slovenian part of the Natura 2000 network, which aims at protecting and preserving rare, endangered and endemic animal and plant species and habitat types. However, the conservation status of some olm habitats is unfavourable given that the number of specimens is declining. For this purpose we prepared hydrogeological conceptual models, where recharge areas were delineated and quantitative as well as qualitative status of surface and ground-waters were studied. Knowing the basic characteristics of olms, their habitats and critical parameters that adversely affect their conservation status, we identified locations where critical parameters could exceed the threshold values in groundwater. We also identified the areas where and what are the trends of the observed parameters that exceed the natural background (As, Zn) or are undoubtedly of anthropogenic origin (PCB).

Key words: groundwater, groundwater dependent ecosystems, olm, Water Framework Directive

Izvleček. Ekosistemi, odvisni od podzemne vode – indikatorji stanja podzemne vode – V okviru priprave »Načrta upravljanja voda za vodni območji Donave in Jadranskega morja 2015-2021 (NUV II)« smo preučevali tudi kemijsko in količinsko stanje podzemnih voda kraških vodonosnikov, ki so habitat ekosistemov, odvisnih od podzemne vode (EOPV). Med temi habitati je tudi habitat človeške ribice (*Proteus anguinus*), ki velja za endemit dinarskega krasa. Habitati človeških ribic so uvrščeni v slovenski del omrežja Nature 2000, katerega cilj je varovati in ohraniti redke, ogrožene ali endemične vrste živali in rastlin ter habitatnih tipov. Kljub temu je stanje ohranjenosti nekaterih habitatov človeških ribic neugodno, saj število osebkov upada. V ta namen smo na podlagi razpoložljivih podatkov izdelali hidrogeološke konceptualne modele, kjer smo določili prispevna območja virov podzemne vode, od katerih so odvisni ekosistemi, in preučili kemijsko in količinsko stanje podzemne ter površinske vode na podlagi rezultatov različnih monitoringov. S poznavanjem osnovnih značilnosti človeških ribic in njihovega habitata ter z naborom poznanih kritičnih parametrov, ki neugodno vplivajo na njihovo stanje ohranjenosti, smo ugotavljali, na katerih mestih so mejne vrednosti kritičnih parametrov v podzemni vodi presežene ter kje in kakšni so trendi koncentracij onesnaževal v podzemni vodi, ki presegajo naravna ozadja (As, Zn), ali pa so zagotovo antropogenega izvora (PCB).

Ključne besede: podzemna voda, ekosistemi, odvisni od podzemne vode, človeška ribica, Vodna direktiva

Introduction

Groundwater presents the main source of drinking water in Slovenia since it supplies more than 97% of its population (Krajnc et al. 2008). It is also very important for agricultural and industrial use. Actually, more attention is given to the groundwater dependent ecosystems (GDEs) which also play an important role in characterization of the groundwater body status (ARSO 2009). These GDEs require permanent or intermittent access to groundwater to meet all or some of their water requirements, so as to maintain their communities of plants and animals, ecological processes and ecosystem services (Richardson et al. 2011). GDEs include groundwater ecosystems (GWE), groundwater dependent terrestrial ecosystems (GWDTE) and groundwater associated aquatic ecosystems (GWAAE).

Habitats of olms, GDEs studied in this paper, are part of the Natura 2000 protected areas (the EU's ecological network). The aim of Natura 2000 Management Programme for Slovenia for the 2015–2020 period is to ensure the favourable conservation status of species and habitat types (Vlada RS 2015). It includes various GDEs, such as forests, wetlands, caves, aquatic animals, petrifying springs with tufa formation (*Cratoneurion*), etc. Subject of our research were endemic species of olms (*Proteus anguinus*), karst GDEs that have unfavourable conservation status and require restoration and/or preservation. Amphibians are found in groundwater of karst channels and caves in the SW, S and SE parts of Slovenia. Chemical status of groundwater in vulnerable karst aquifers in Slovenia is good on the regional scale but experts claim that olm population, which undoubtedly depends on groundwater status, is declining in some areas (Sket 1997, Bulog 2012). For this reason we studied, within the framework of »Water Management Plan for the Danube River Basin and the Adriatic Sea 2015-2021 (NUV II)«, the relationship between the groundwater quality and quantity and ecosystem’s conservation status.

Materials and methods

Olms are also known as proteus, human fish or salamander (*Proteus anguinus*). This cave-dweller is considered an endemic species of Dinaric karst (ZRSVN 2008). It lives only in groundwater along the Adriatic Sea (Sket 1997). Olms can be found in more than 70 caves in Slovenia (ZRSVN 2008). Beside the white olm (*Proteus anguinus anguinus*), there is also a black pigmented subspecies of olm (*Proteus anguinus parkelj*), which is located around Črnomelj and is known as endemic species of Bela krajina in SE Slovenia (Sket et al. 2003). Olms live in the karst groundwater cave systems and prefer calm and well oxygenated water with stable temperature (Honegger 1981, Sket 1997). They live in phreatic zones that are occasionally flooded into epiphreatic zones during peak discharges, so they depend exclusively on fresh groundwater and do not survive on the dry land (Aljančič et al. 2014). Ecosystems of olms (Tab. 1, Fig. 1) are found in the karst areas where surface water mostly or completely sinks into the ground. Conservation status of olms is classified into 3 priority classes (ZRSVN 2014). 9 GDEs have unfavourable conservation status (the 1st and the 2nd priority), whereas 16 ecosystems achieve favourable conservation status. In our study we focused on olms in unfavourable conservation status, where their population is believed to be declining. Experts estimate that the critical oxygen concentration in groundwater for olms is 2.9 mg O_2/L (at 10° C), but they can also survive in groundwater with less than 1% O_2/L (Bulog 2007). Experts also estimate that groundwater nitrate concentrations (NO_3^-) above 10 mg/L can harm the adult olms as well as the larval stages (Hudoklin 2011).

For the identification and understanding the dependence of GWE on groundwater it was necessary to collect available information on hydrogeological and hydrodynamic characteristics of aquifers in the areas of GDEs. Based on results of past tracer tests and studies for water protection areas, groundwater recharge areas of groundwater resources on which GWEs depend on were delineated and conceptual models were elaborated. Conceptual models describe in the first place the aquifer type, groundwater flow directions and groundwater - surface water interaction. Groundwater chemical and quantity status was studied based on on-site or nearest monitoring sites to GWEs and, moreover, also using surface water monitoring sites where aquifer is recharged by surface water. Monitoring programme is implemented and performed by the Slovenian Environment Agency (ARSO) for ecological, chemical and quantity status, and by the Biotechnical Faculty (University of Ljubljana) for water quality. Additionally, we also examined whether the GDEs are located in the water protected areas, where the abstractions could have a certain impact. Further, we reviewed the published literature and available data from other groundwater monitorings (sources cited in Mezga et al. 2015), land use and possible sources of pollution in the GDEs' recharge areas such as settlements, agricultural land use, industrial facilities, landfills and emissions from facilities. Based on the known environmental supporting conditions as well as critical parameters and threshold values for the olm population, we identified locations with exceeded threshold values for the critical parameters and prepared a list of possible sources for ecosystem deterioration (Tab. 1).

Table 1. List of habitats of olms in the Natura 2000 area in unfavourable conservation status (ZRSVN 2014), possible sources of ecosystem deterioration and measured concentrations of some pollutants in surface- and groundwater.
Tabela 1. Seznam habitatov človeških ribic na območju Nature 2000 v neugodnem stanju ohranjenosti (ZRSVN 2014), možni viri obremenitev ekosistemov in merjene koncentracije nekaterih onesnaževal v površinski in podzemni vodi.

GB ID*	Ecosystem (Natura 2000)	Priority	Possible sources for ecosystem deterioration*	Measured concentrations of some pollutants in surface- and groundwater
1010	Notranjski trikotnik	2	fertilizing Planinsko polje with chicken manure, intensive farming, uncontrolled discharges of municipal wastewater treatment plant, direct runoff from the sewage system, landfills, illegal dumpsites; occurrence of metals in water, poor ecological status of rivers Pivka, Cerkniščica, Reka	Pivka River at Planinsko polje (Bulog 2007, 2012): <5.0 µg Zn/L, <0.5–3.6 µg Cu/L, 3.17 µg Hg/L, 0.25–0.76 µg As/L
1011	Vir pri Stični	1	intensive agriculture, illegal discharges from the sewer system into the underground, settlement with unregulated sewage system, illegal dumpsites, caves and abysses filled with garbage, cultivation of birds and rabbits close to spring	Vir (2003–2006; Seibert 2008): 6.2–25.5 mg NO_3^-/L, 0.06–2.38 mg PO_4^{3-}/L

GB ID*	**Ecosystem (Natura 2000)**	**Priority**	**Possible sources for ecosystem deterioration***	**Measured concentrations of some pollutants in surface- and groundwater**
1011	Gradac	2	old sources of pollution (landfills, installations, industrial sites, emission sites, etc.), settlement, agriculture, caves filled with garbage	Krupa (ARSO 2015): presence of PCB
	Dobličica (Jelševnik)	2	old unremediated pollution sources, uncontrolled discharges of urban waste, illegal dumping of waste, renovation of the road above the spring, manure and slurry spills; occurrence of metals in water	Jelševnik (2001–2015; Bulog 2007, 2012; ARSO 2015): 0.9–16 mg NO_3^-/L; 0.01–2.5 mg PO_4^{3-}/L; <5.0–14.6 µg Zn/L; <0.5–9.8 µg Cu/L; 0.29–5.05 ng Hg/L; <0.01–1.20 µg As/L
	Kotarjeva prepadna	2	agricultural and urban areas, illegal dumping of waste, caves filled with garbage	n.d.*
	Stobe - Breg	2	manure and slurry spills, caves filled with garbage, illegal dumping of waste, agriculture and irrational use of fertilizers and pesticides, uncontrolled discharges of municipal wastewater treatment plant, old impacts (insecticide)	Pački potok (2000-2009; Bulog 2012): 2.7 mg PO_4^{3-}/L; Pački breg (2014; ARSO 2015): 4.5–16.5 mg NO_3^-/L, 0.04–0.52 mg PO_4^{3-}/L; Otovški breg (2014; ARSO 2015): 6.5–20.5 mg NO_3^-/L, 0.02–0.32 mg PO_4^{3-}/L
	Petanjska jama	2	agricultural and urban areas, illegal dumping of waste, caves filled with garbage	n.d.*
	Kočevsko	2	manure from pig farm, cattle farming, unremediated old deposits in pits, effluent of waste water into a pit, discharges from municipal waste water treatment plant, municipal landfill, industrial facilities, cave Jama pod Starim Bregom used for industrial landfill for chipboard, resin and melamine panels; poor ecological status of Rinža River	Listed locations (2015; Prelovšek 2015): Vodna jama (pri Klinji vasi) 12.64–16.97 mg NO_3^-/L; Vodna jama pri Cvišlerjih 11.66–22.33 mg NO_3^-/L; Velika Stankova jama 12.30–15.56 mg NO_3^-/L; Remihov mlin 172.36 mg SO_4^{2-}/L; Vodna jama (pri Klinji vasi) 111.15–242.18 mg SO_4^{2-}/L; Željnske jame 12.66–216.61 mg SO_4^{2-}/L; Jama v Šahnu 0.13–2.14 mg PO_4^{3-}/L; Vodna jama pri Cvišlerjih 0.10–2.94 mg PO_4^{3-}/L
5019	Kras	2	landfills, direct discharges of waste water from industrial and municipal waste water treatment plants in the cave, use of fertilizers and pesticides (golf course, horse breeding), winegrowing, unregulated dung and manure storage pits	Jama 1 v Kanjaducah (2004; Mihevc & Rijavec 2006): 207 mg NO_3^-/L, 63 mg SO_4^{2-}/L, 5 mg PO_4^{3-}/L, 204 mg Cl^-/L

* All sources are listed in Mezga et al. (2015); GB – Groundwater Body; n.d. – no data

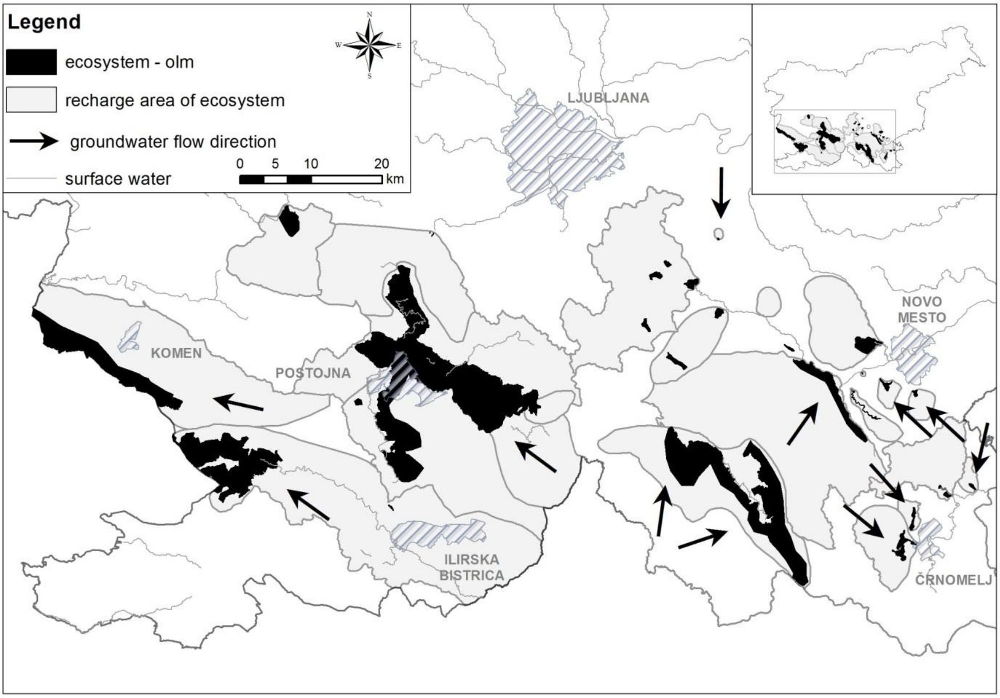

Figure 1. Habitats of olms in the Natura 2000 (ZRSVN 2014) and their recharge areas (Mezga et al. 2015).
Slika 1. Habitati človeških ribic na območju Nature 2000 (ZRSVN 2014) in njihova prispevna območja (Mezga et al. 2015).

Results and discussion

The main pressures on olms in unfavourable conservation status could be linked to poor groundwater quality arising from unremediated old impacts of pollution, illegal dumping of waste, intensive agriculture, unregulated disposal of manure, slurry and pesticides, waste water treatment plants malfunctions, unregulated drainage of industrial and municipal waste disposal sites (especially into caves), which make these GWEs highly vulnerable.

Detailed analysis of the results of national monitoring show that groundwater status at three monitoring sites (Krupa, Otovški breg and Pački breg) can have unfavourable impact on the conservation status of ecosystems due to the presence of polychlorinated biphenyls (PCB) and increased nitrate concentrations (NO_3^-) in groundwater (ARSO 2015). Additionally, the results of other monitorings (Mihevc & Rijavec 2006, Bulog 2007, Seibert 2008, Bulog 2012, Prelovšek 2015) showed that groundwater chemical status is locally deteriorated by increased concentrations of nitrate (NO_3^-), phosphates (PO_4^{3-}), chlorides (Cl^-), sulphates (SO_4^{2-}) (Jama 1 v Kanjaducah, Vodna jama (pri Klinji vasi), Vodna jama pri Cvišlerjih, Željnske jame, Jama v Šahnu, etc.) and metals (As and Zn) (Jelševnik). In the areas of the ecosystems, where no monitoring of groundwater has been carried out, we can assess the status of groundwater based on analysis of the pressures and impacts.

In order to achieve the environmental objectives according to the Water Framework Directive (EU WFD 2000, Article 4) and Decree on groundwater status (Ur. l. RS 2009, 2012), as part of the Water Management Plan for the Danube River Basin and the Adriatic Sea, supplementary measures need to be introduced to prevent any groundwater deterioration that has unfavourable impacts on GDEs. Thus, continuous upgrade of knowledge on GDEs is needed in the following years, including hydrogeological and ecological conceptual models of ecosystems as well as determination of critical parameters and their threshold values. In order to prepare quality basis for the preparation of the necessary supplementary measures, a close collaboration between experts of both mentioned interdisciplinary fields is required.

Groundwater monitorings in the recharge areas of groundwater resources, on which GWEs depend on, have pointed out an important role of GWEs in identifying local groundwater status. Specifically, the conservation status of ecosystems (favourable or unfavourable) can provide additional information on the groundwater status at the local level and can serve as an indicator of local groundwater status. Additional definition of critical parameters and their threshold values for olms would allow narrowing the list of sources of pollution which are affecting groundwater status and consequently ecosystems. The fact that olms are extremely sensitive and vulnerable to changes in the environment (Aljančič et al. 2014) and that their threshold critical values are much lower in comparison with the quality standards or threshold values according to the Decree on groundwater status (Ur. l. RS 2009, 2012), can help us to identify reliable local groundwater status.

In order to restore and preserve damaged GDEs, including endemic species, a favourable conservations status needs to be achieved. This could only be reached when there is sufficient quantity of groundwater of good quality, which also requires knowledge on critical threshold values of critical parameters for individual species and habitats conservation in groundwater.

Acknowledgements

The research presented in this paper was prepared within the framework of »Water Management Plan for the Danube River Basin and the Adriatic Sea 2015–2021 (NUV II)«, financially supported by the Ministry of the Environment and Spatial Planning.

References

Aljančič G., Gorički Š., Năpăruş M., Stanković D., Kuntner M. (2014): Endangered *Proteus*: combining DNA and GIS analyses for its conservation. In: Sackl P., Durst R., Kotrošan D., Stumberger B. (Eds.), Dinaric Karst Poljes – Floods for Life, Proceedings of the 1st workshop on karst poljes as wetlands of national and international importance, Livno, pp. 71-75. http://ezlab.zrc-sazu.si/uploads/2014/06/Aljancical2014_Proteus_splited.pdf [accessed on 12. 11. 2014].

ARSO (2009): Metodologija za ugotavljanje stanja vodnih teles podzemne vode. Agencija RS za okolje (Slovenian Environmental Agency), 28 pp. http://www.arso.gov.si/vode/podzemne%20vode/Metodologija.pdf [accessed on 14. 10. 2015].

ARSO (2015): Podzemne vode – izpisi podatkov po vodnih telesih za leto 2014. Agencija RS za okolje (Slovenian Environmental Agency). http://www.arso.gov.si/vode/podatki/arhiv/kakovost_arhiv2014.html [accessed on 12. 6. 2015].

Bulog B. (2007): Okoljske in funkcionalno-morfološke raziskave močerila (*Proteus anguinus*). Proteus 70(3): 102-109.

Bulog B. (2012): Ocena okoljskega onesnaženja kraškega podzemlja v Jelševniku pri Črnomlju in vplivi na črno podvrsto močerila (*Proteus anguinus parkelj*, Amphibia, Proteidae) (report). University of Ljubljana, Biotechnical Faculty, Department of Biology, 17 pp.

EU WFD (2000): Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy (EU Water Framework Directive). http://ec.europa.eu/health/endocrine_disruptors/docs/wfd_200060ec_directive_en.pdf [accessed on 7. 3. 2015].

Honegger R.E. (1981): Threatened amphibians and reptiles in Europe. European Committee for the Conservation of Nature and Natural Resources Council of Europe. In: Böhme W. (Ed.), Supplementary Volume of Handbuch der Reptilien und Amphibien Europas, Akademische Verlagsgesellschaft, Wiesbaden, 158 pp.

Hudoklin A. (2011): Are we guaranteeing the favourable status of the Proteus anguinus in the Natura 2000 network 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, Collegium Graphicum, pp. 169-181. http://iks.zrc-sazu.si/datoteke/Protection-of-the-underground-karst.pdf [accessed on 12. 3. 2015].

Krajnc M., Gacin M., Dobnikar-Tehovnik M., Krsnik P. (2008): Groundwater chemical status assessment in Slovenia. Proceedings of invited lectures of symposium on groundwater flow and transport modelling - Groundwater modelling. Ljubljana, pp. 29-38. http://www.arso.gov.si/en/water/reports%20and%20publications/Groundwater_Modelling.pdf [accessed on 14. 10. 2015].

Mezga K., Janža M., Šram D., Koren K. (2015): Priprava strokovnih podlag in strokovna podpora pri izvajanju vodne direktive za področje podzemnih voda (Direktiva 2000/60/EC), 2. UKREP DDU26: Analiza razpoložljivih zalog podzemne vode in površinske vode ter obstoječe in predvidene rabe vode za obdobje do 2021 - Pregled ekosistemov odvisnih od stanja podzemnih vod (report). Geological Survey of Slovenia, Ljubljana, 77 pp.

Mihevc A., Rijavec J. (2006): Poročilo o analizi vzorcev iz Jame 1 v Kanjeducah (kat. št. 276). Naše jame 46: 131-133.

Prelovšek M. (2015). Prvo vmesno poročilo o kvaliteti podzemnih voda v izbranih vodnih jamah Kočevskega polja in izviru Bilpe in Radeščice/Obrha (report). Postojna, Karst Research Institute - ZRC SAZU, 41 pp. http://life-kocevsko.eu/wp-content/uploads/2015/12/2015_10_06_PrvoVmesnoProciloOKvalitetiPodzemnihVoda.pdf [accessed on 26. 6. 2016].

Richardson S., Irvine E., Froend R., Boon P., Barber S., Bonneville B. (2011): The Australian groundwater-dependent ecosystems toolbox part 1: Assessment Framework. Waterlines Report Series No. 69, Natural water Commission Canberra, 101 pp. http://nwc.gov.au/__data/assets/pdf_file/0006/19905/GDE-toolbox-part-1.pdf [accessed on 2. 2. 2015].

Seibert J. (2008): Fizikalni in kemijski parametri na lokaliteti močerila (*Proteus anguinus*) v Viru pri Stični. Graduation thesis. University of Ljubljana, Biotechnical Faculty, 78 pp.

Sket B. (1997): Distribution of *Proteus* (Amphibia: Urodela: Proteidae) and its possible explanation. J. Biogeogr. 24(3): 263-280.

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

Ur. l. RS (2009): Uredba o stanju podzemnih voda. Uradni list RS 19(25): 3332-3345.

Ur. l. RS (2012): Uredba o dopolnitvah Uredbe o stanju podzemnaih voda. Uradni list RS 22(68): 7005.

Vlada RS (2015). Program upravljanja območij Natura 2000 (2015-2020), Vlada Republike Slovenije, 30 pp. http://www.natura2000.si/fileadmin/user_upload/LIFE_Upravljanje/PUN__ProgramNatura.pdf [accessed on 5. 9. 2015].

ZRSVN (2008): Jame kot naravne vrednote in območja Natura 2000. Zavod RS za varstvo narave (Institute of the Republic of Slovenia for Nature Conservation), 10 pp. http://www.zrsvn.si/dokumenti/63/2/2008/clanek_jame_koncni_1227.pdf [accessed on 10. 10. 2015].

ZRSVN (2014): Areas of groundwater dependent ecosystems (digital polygon layer), Zavod RS za varstvo narave (Institute of the Republic of Slovenia for Nature Conservation).