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ABANDONED WATER RESOURCES AS POTENTIAL SOURCES OF DRINKING WATER – THE KORENTAN KARST SPRING NEAR POSTOJNA

OPUŠČENI VODNI VIRI KOT POTENCIALNI VIRI VODOOSKRBE – KRAŠKI IZVIR KORENTAN PRI POSTOJNI

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The Korentan karst spring near Postojna.
Kraški izvir Korentan pri Postojni.

Abandoned water resources as potential sources of drinking water – the Korentan karst spring near Postojna

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ABSTRACT: In the area of the Orehek karst intrinsic vulnerability maps of groundwater and the Korentan karst spring, hazard maps and risk to contamination map have been made using Slovene Approach. For this purpose cartographic and other published data on geological, geomorphological, pedological, hydrological and meteorological characteristics have been gathered and extensive field inventory of the missing geomorphological and pedological characteristics has been made. Publically available land use and census data have been examined and checked in the field, manure heaps and illegal waste dumps have been mapped. The final thematic maps are excellent tools for national and local authorities when planning water protection and land use. The presented study in the catchment of an actual water source is an example of good practice of the revival of the in the past abandoned water sources that can in the future serve as a substitution water source in case of main water source overexploitation or contamination.

KEY WORDS: drinking water, karst spring, vulnerability assessment, risk to contamination assessment, hazard mapping, water protection, water management.

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1 Introduction

In Slovenia and worldwide a key issue in water supply is how to ensure adequate quality and quantity of drinking water. Due to rapid decreasing of water reserves in porous and other aquifers and their increasing pollution, the importance of karst water resources is growing (Bakalowicz 2005; Ford and Williams 2007; Kresic 2009; Guo, Yuan and Qin 2010; Dar et al. 2011). One of the advantages of bigger karst springs is sufficient amounts of water also during the time of low waters. On the other hand these springs have large catchments and their effective protection against pollution is a great challenge. As a result, water quality of these springs is often not good (Ravbar and Kovačič 2006).

Since a modern water supply bases on permanent and abundant water resources, past water resources based on tapping of small amounts of surface, precipitation or groundwater, lost their importance. In case of pollution, an entire area depending on a single water resource remains without drinking water or its quality is limited and water supply of larger area is interrupted.

A recent case was a relative long-term pollution of the Malenščica karst spring ($Qs_{1971–2000}$ = 6.62 m^3/s; catchment area 726 km^2) at the end of 2011 and the beginning of 2012. The spring is captured for the water supply of Postojna, Pivka and partly Ilirska Bistrica municipalities (22,000 users). Contamination of the spring was a result of washing of the accumulated pollution out of the system in a time of increased discharges, following the first relatively intensive precipitation event after a long period without precipitation. The spring was polluted and inadequate for the water supply for 35 days (from December 20 to December 31, 2011; from January 12 to February 3, 2012), until additional cleaning of water was ensured at its water capture. Consequently safe water supply has been disturbed.

With a linkup of different water resources into a common water supply system consequences of above described and similar events can be mitigated. In future plans for water supply numerous local water resources in connection to traditional forms of water supply should be included into a water supply system besides existing regional water resource. Therefore a holistic strategy of water supply on national level, comprising of protection and management of water resources and provisions at incidents should be elaborated.

In the case of the Malenščica spring contamination, minimal needs for clean water can be ensured with an activation of reserve water resources. Korentan karst spring (the Orehek karst aquifer) was a part of Postojna water supply system in the past, but since 1972 it has been abandoned (Petrič and Šebela 2004; Kovačič and Petrič 2007). Regarding the quality and quantity of water in spring and its relative unburdened catchment, the spring can be used as a reserve water resource. The spring is protected on the basis of the local legislation (Ordinance on the protection of local water sources in the Postojna municipality 1998) but for the effective protection of the Orehek karst area water reserves quality, it is important to distinguish its most vulnerable parts, existing hazards and to propose most adequate land use in the area. Therefore, in a presented study we assessed intrinsic vulnerability of the Orehek karst groundwater and the Korentan spring, compiled an inventory of hazards and made a risk to contamination map for the Korentan spring.

Results of this investigation present a good basis for preparing basic plans for prudent management of water resources in similar cases in the future, in order to, firstly, ensure to ourselves and future generations uninterrupted drinking water supply and secondly, to preserve adequate amounts of qualitative water reserves.

2 Study area

Orehek karst area is a well defined shallow karst aquifer, situated northwest of the Pivka valley (Figure 1). It covers an area of around 10 km^2. A slightly uplifted ridge reaches up to 725 m in height above the surrounding 545–600 m altitudes. The aquifer consists of an anticline of Cretaceous and Palaeocene limestones (Figure 2), which is in the southwest partially thrusted over Eocene flysch and encircled by it (Gospodarič, Habe and Habič 1970; Petrič and Šebela 2004). The Orehek karst is well-karstified with numerous dolines (461) and 70 caves registered in the Slovene Cave Cadastre (2012). The carbonate rocks in its northern part are covered with a thin layer of rendzina soil, and in the southern part with brown carbonate soil of various depths. The Orehek karst lies on the border between sub-continental and inland sub-Mediterranean climates; average annual precipitation is about 1,600 mm.

Figure 1: Panoramic view of the Orehek karst.

The aquifer is additionally recharged by several small sinking rivers on the SW (e.g., Čermelice, Orehovške ponikve). On the northeastern margin of the aquifer very low permeable flysch acts as a hydrological barrier. Two temporal springs (Poliček and Mrzla jama) and a permanent Korentan spring drain the aquifer. Tracer test results proved the connection of the southern part of the aquifer and the Orehovške ponikve sinking stream with the Poliček spring at high waters. At low waters, the underground waters of the southern part of the aquifer flow towards the Pivka River situated further to the east (not shown on Figure 2) (Gospodarič, Habe and Habič 1970). The second tracer test performed at medium waters and proved the connection of Čermelice sinking rivers with the Korentan spring. The groundwater flow velocity was estimated to 25 m/h and the tracer recovery to 71% (Schulte 1994).

The main outflow from the Orehek karst aquifer is the Korentan spring which is a typical karst spring, characterized by rapid, sharp responses to precipitation events. Spring discharges range from a few litres per second to about 3 m^3/s with an average of 0.2 m^3/s. Based on the results of tracer test and the water balance method, the extent of the spring's recharge area has been estimated and delineated to 6 km^2 (including the non-karst part of the catchment) (Schulte 1994; Petrič and Šebela 2004; Jemcov and Petrič 2009; Kogovšek and Petrič 2012).

3 Methodology

To effectively protect the most sensitive areas of karst aquifers, several European countries use the concept of assessing vulnerability to determine water protection zones. Furthermore, assessment of contamination risk is increasingly important in land use planning (Zwahlen 2004; Ravbar 2007; Goldscheider 2010). The Slovene approach (Ravbar and Goldscheider 2007) most comprehensively follows these European guidelines and has therefore been applied in this study. The method includes the assessment of karst groundwater or water source vulnerability and degree of hazard. These two assessments form the basis for calculating the contamination risk to groundwater or water sources.

The assessment of natural vulnerability includes the geological, geomorphological, pedological, hydrogeological, and meteorological characteristics of a karst system and is independent of the properties and behaviour of individual contaminants (Table 1, see also Figure 3). Relative to the purpose, two types of vulnerability assessment are available: for resources and for sources. Assessment of resource vulnerability includes parameters that control the flow of infiltrated water from the surface all the way to the water table. Here, relevant factors include the permeability and thickness of the soil and rock composing the unsaturated (vadose) zone and the concentration of runoff in the underground as influenced by topography, the vegetation cover, and the distribution and intensity of precipitation. The additional parameter, which considers the characteristics of water flow in the saturated (phreatic) zone, makes it possible to assess the vulnerability of a water source (Figure 3).

Evaluation of the protective function of the layers overlying the groundwater of the Orehek karst aquifer has been based on information from geological and soil maps and verified in the field by means of geological and geomorphological mapping, as well as soil depth measurements using hand auger. Additional information has been obtained from topographic maps, digital orthographic photographs and the national cave database (SCC 2012). The thickness of the unsaturated zone has been determined by subtracting

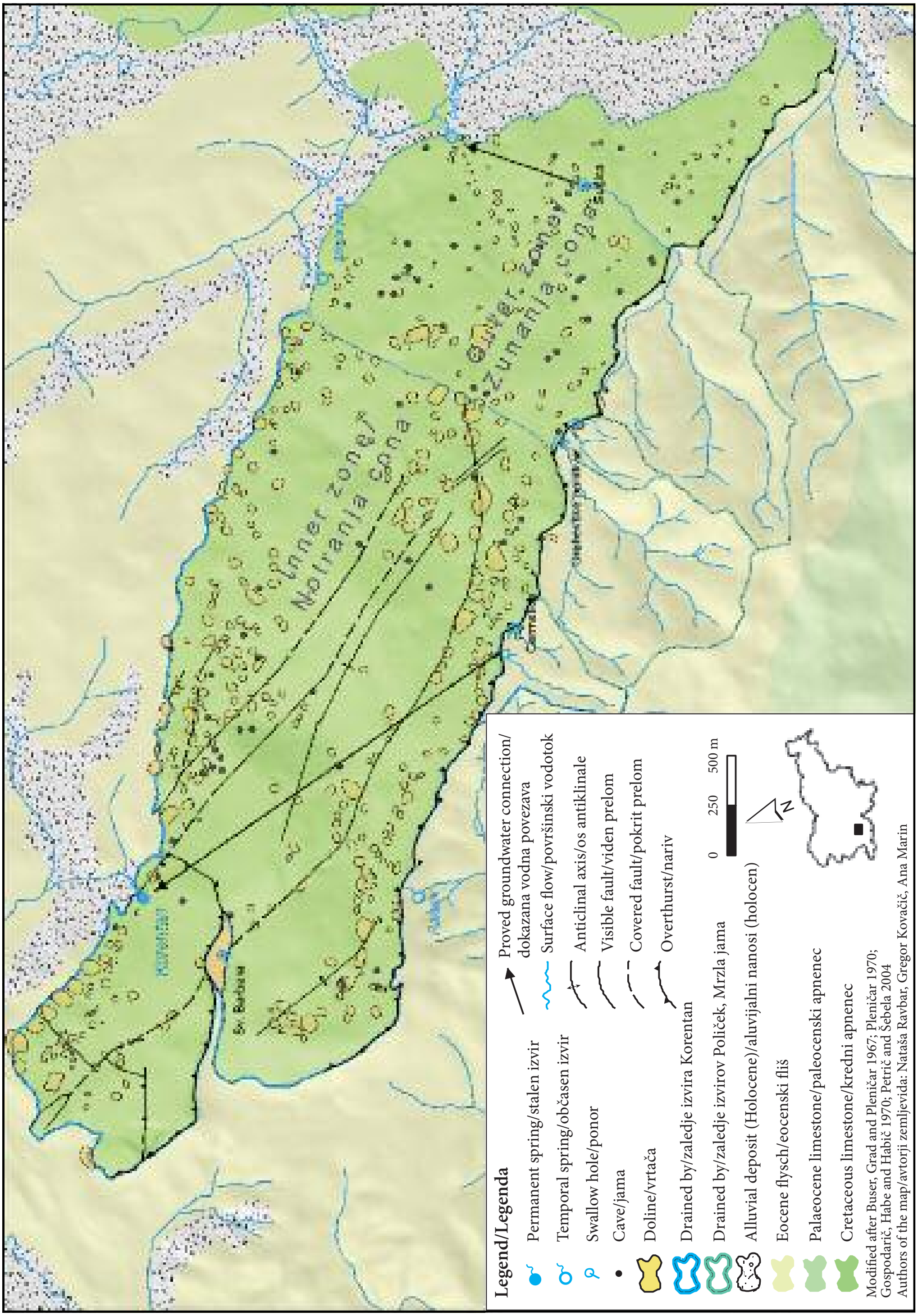

Figure 2: Hydrogeological and geomorphological settings of the Orehek karst and its surroundings.

the grid of the estimated groundwater level from the grid of the digital elevation model (based on surroundings' springs and ponors altitudes).

The infiltration conditions and concentration of flow have been evaluated on the basis of the digital elevation model, topographic maps and land use database of 2012 (Internet 1). Flow processes have been assessed by means of geological information and direct field observations. For the precipitation regime and recharge characteristics, the yearly and daily precipitation data (period 1961–2010) from the Postojna meteorological station have been used (EARS 2010).

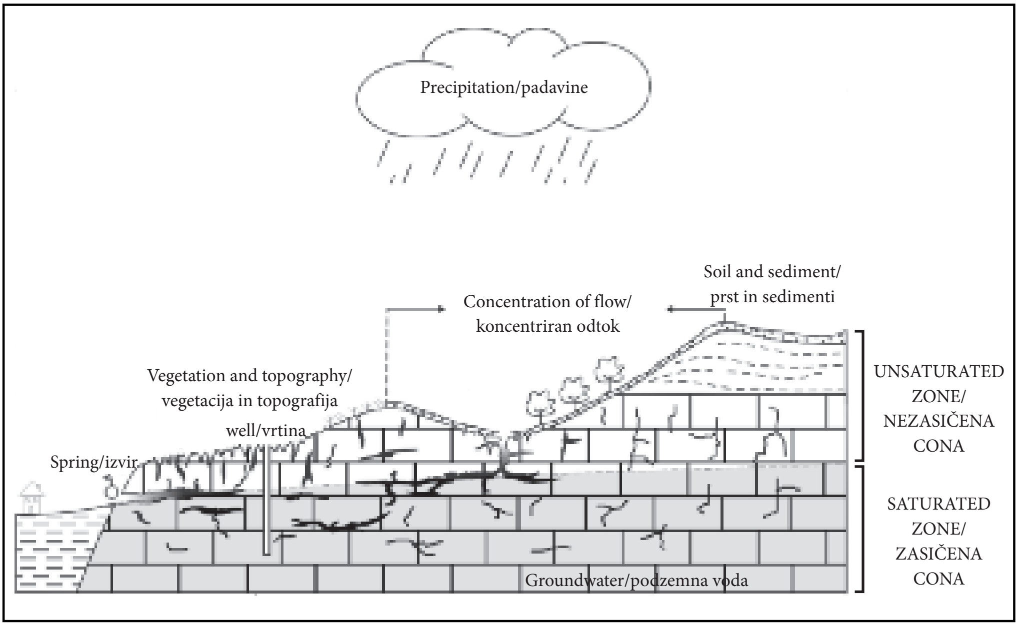

Figure 3: Conceptual model of a karst aquifer and parameters influencing the vulnerability of water resources or sources (modified after Andreo, Ravbar and Vías 2009).

Table 1: Data included in the Orehek karst and Korentan spring vulnerability assessment.

	Data		
KARST UNSATURATED ZONE	Topsoil thickness Topsoil texture Topsoil structure Subsoil permeability Subsoil thickness Depth of the unsaturated zone Fracturation Epikarst development/geomorphological features Confined situation	Orehek karst vulnerability assessment	Korentan spring vulnerability assessment
RECHARGE CONDITIONS	Concentration of flow Slope gradient Land use/vegetation cover Autogenic recharge Alogenic recharge Temporal variability		
KARST SATURATED ZONE	Presence of active karst network Hydrological characteristics of a source Tracer test interpretation		

The characteristics of groundwater flow in the saturated zone of the karst aquifer have been assessed on the basis of geological and geomorphological settings, hydrograph analyses of the Korentan spring daily discharges in hydrological year 2004 (23. 9. 2003–31. 8. 2004) (Petrič and Šebela 2004), hydrological budgeting in the period 1961–2010 and interpretation of the tracer test (Schulte 1994). Additional information has been gained from the national cave database (SCC 2012).

Vulnerability mapping is not always a sufficient criterion for proper land use planning, since it does not show the degree to which the aquifer is already under pressure. Therefore hazard assessment has been made in the frame of this study. The goal of hazard mapping is to identify and illustrate the locations and types of human activities that pose a threat to groundwater quality. The hazard evaluation considers the type, noxiousness and quantity of the contaminants, as well as the likelihood of a contaminant release (De Ketelaere et al. 2004).

The information for hazard mapping in the Orehek karst has been obtained from topographic maps, land use database (Internet 1) and direct field observations. In mapping contamination hazards, a specific value is assigned to each source of pollution relative to the qualitative comparison of potential damage (toxicity of substances, their solubility and mobility); comparison within one type of pollutant, however, requires a classification process relative to the level of toxicity of substances and time of exposure to pollution or relative to the quantity or size of the source of pollution. Another factor to consider is probability of pollution as influenced by technical status, maintenance level, safety conditions, and other circumstances. Locations and properties of actual and potential hazards were checked and gathered with fieldwork.

When Korentan vulnerability map has been complemented by hazard map, it has been possible to assess the source's risk of contamination. Thus it has been possible to make a comprehensive assessment of existing human impacts and identify areas that endanger the quality of the potential water source near Postojna at most.

For data handling, evaluation and graphical processing ArcGIS 9.3 has been used.

4 Results

4.1 Vulnerability map

The resource vulnerability map, aiming to protect the whole groundwater body (Figure 4), shows that only 4.4% of the catchment is extremely vulnerable. These areas correspond to caves, bare areas (with no soil cover), such as excavation sites and roads, and to sinking rivers, swallow holes and their surroundings. High vulnerability embraces most of the study area (81.3%). Moderate vulnerability is assigned to 12.9%, i.e. to dolines and some parts of the sinking rivers catchments. Dolines are classified as less vulnerable than the rest of the karst area due to considerable thickness of protective layer on their bottoms (i.e. > 1 m of soil). Areas of low vulnerability extend over 1.4% of the area in the remote parts of the sinking rivers catchments, with the impermeable grounding. Vulnerability of non-karst area depends mainly on vegetation cover and slope inclination.

For the source vulnerability mapping (aiming to protect a particular spring, i.e. the Korentan spring) the Orehek karst aquifer has been subdivided into an inner and an outer zone. The zonation has been made on bases of the geological and geomorphological settings, tracer tests results and the Korentan springs' hydrodynamic behaviour (see references above). The inner zone is the area that always contributes to the investigated spring and is directly connected to and drained by the spring. The outer zone comprises drainage areas in the rest of the aquifer that is not drained by the investigated spring (see Figure 2). Vulnerability degrees in the outer zone therefore decrease in comparison to areas of the inner zone.

In the source vulnerability map (Figure 5) highly vulnerable areas occupy 1.6% of the study area and correspond to caves, excavation site and roads in the Korentan catchment, and to sinking Čermelice river, swallow holes and their surroundings. Moderate vulnerability is assigned to 54.2% of the studied area, i.e. to the major part of the Korentan catchment and to bare areas, caves, sinking rivers, swallow holes and their surroundings outside the Korentan catchment. Areas of low vulnerability extend over 44.2% of the area and cover dolines in the Korentan catchment and majority of the Orehek karst outside the Korentan catchment.

The source vulnerability map can be used as a basis for the delineation of source protection zones.

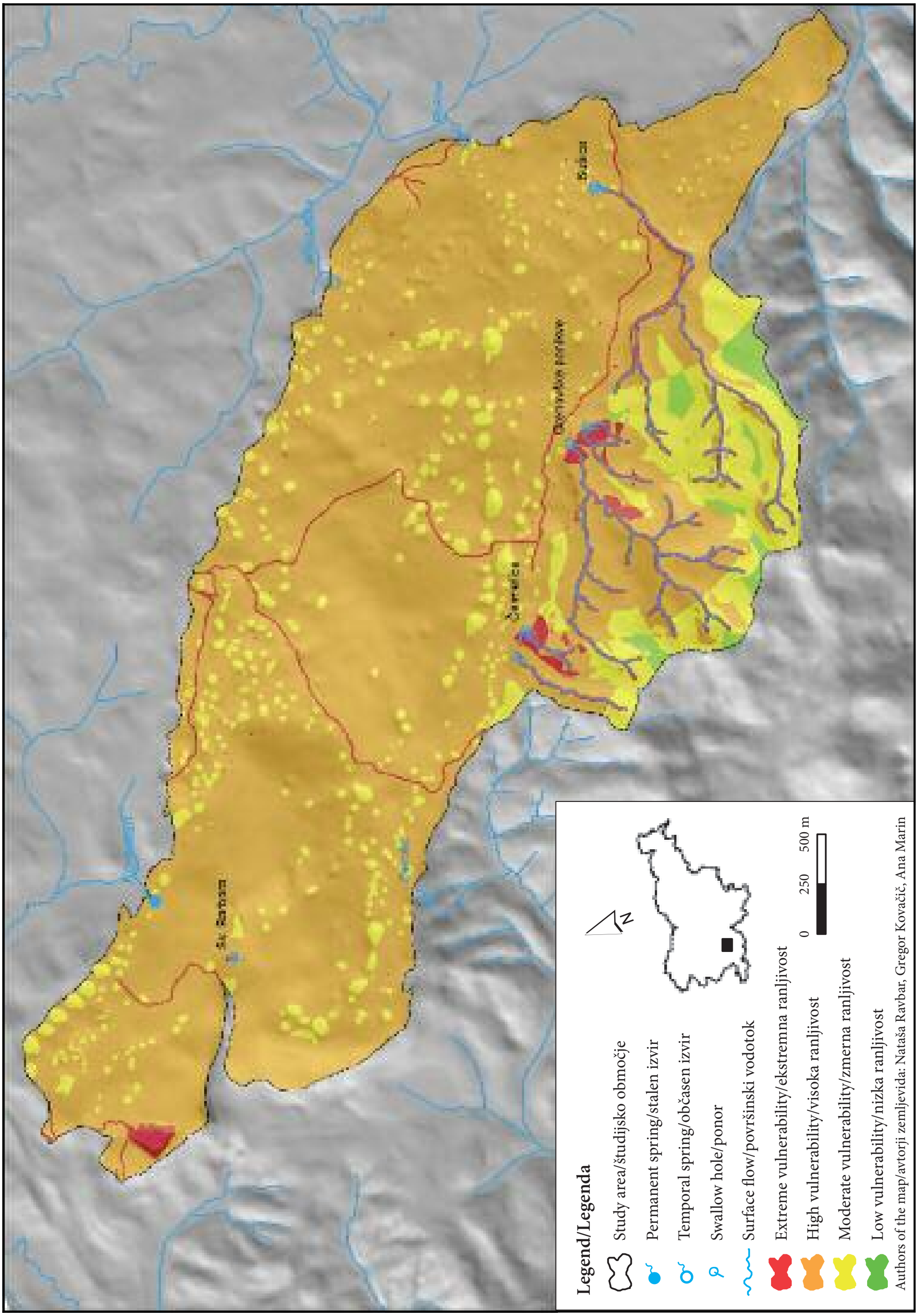

Figure 4: Resource vulnerability map of the Orehek karst.

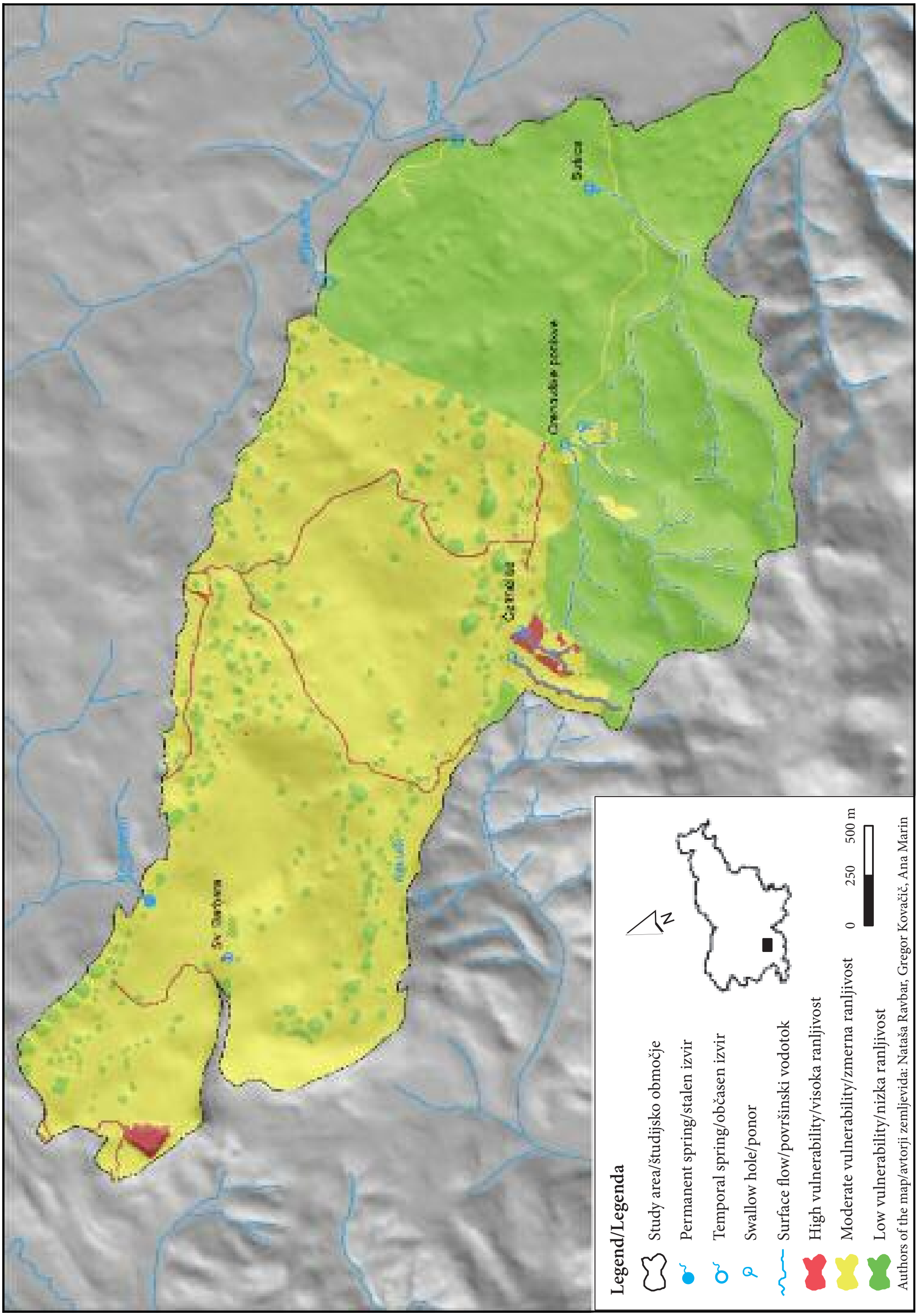

Figure 5: Source vulnerability map of the Korentan spring.

4.2 Hazard map

Major part, 92% of the Orehek karst area is covered by forest (mainly beech). Agricultural activity is low and mostly limited to vicinity of settlements Prestranek, Hruševje and Orehek, which lay on the border of the Orehek karst aquifer. In the vicinity of the settlements a few fields and extensive orchards can be found. Meadows and pastures cover about 6% of the area (Internet 1).

Only a few residential houses in Hruševje and Prestranek fall within the borders of the Orehek karst aquifer and approximately a half of the Orehek is also located within the borders of the aquifer. According to the 2011 census around 150 people lived in the area (Internet 2). Settlements are without sewer systems. Only local, macadam roads mainly used by farmers and foresters cross the aquifer, traffic flow is negligible. In terms of water protection, low agriculture activity and dense forest cover are very favourable. However, some actual and potential point and area sources of pollution exist over the aquifer.

In the vicinity of Hruševje there is an abandoned quarry, which is occasionally used as a waste dump (organic waste). In Orehek we found two open manure heaps, another big and unprotected manure heap is located near a farm, 100 m ahead of the Čermelice ponor. Leachate from the manure heap directly drains in a small ditch into the ponor and poses a serious threat to the quality of the Korentan spring.

According to the field survey conducted in 2011, nine illegal waste dumps threaten the quality of the Orehek karst aquifer. Three of them are located in dolines (no. 1, 2 and 8 on Figure 6), two of them in potholes (no. 4 and 7) and one of them in Orehovške ponikve ponor cave (no. 9). The last one poses a serious threat to the quality of the Poliček spring, but according to the known facts, not to the Korentan spring. The number of illegal waste dumps decreased in last years; in 2002 we mapped 34 of them. Majority of then active dumps are now sanitized or abandoned.

Unclassified hazard map (Figure 6) shows the described actual and potential sources of contamination, whereas the classified hazard map (Figure 7) depicts the possible impact of human activities to the waters.

Figure 7 shows the hazards found in the test site are mainly classified as low (2.3%) or very low (0.4%). Settlements without sewer systems, roads, abandoned quarry, illegal waste dumps and manure heaps are classified as low hazards, fields and orchards as very low hazards. In majority of the area, 97.3%, no hazards have been identified.

4.3 Risk to contamination map

The risk to contamination is obtained by combining the vulnerability and the hazard assessment. Thus it is possible to make a comprehensive assessment of existing human impacts and identify areas with inadequate management, reorganize land use and apply better practice in future planning, create a foundation for a variety of environmental impact assessments, and facilitate the predictions of consequences and damage (ecological and material) of a variety of pollution events.

In the studied area, in general the risk degree strongly depends on the hazard level and its distribution. Most of the catchment is exposed to low risk (98.5%); only urban areas, roads, dumps and excavation sites represent medium degree of contamination risk that occupy 1.5% of the study area in total (Figure 8).

5 Conclusion

This study shows how karst water sources of an individual area should be evaluated in terms of their potential use as a reserve water source in cases of contamination of regional water source. With the use of cartographic and other published material and by conducting field work, intrinsic vulnerability of karst water resources, evaluation of hazards and risk to contamination assessment should be made, and result shown on intelligible thematic maps.

The intrinsic vulnerability assessment can be transformed into water protection zones. The identification of the most vulnerable areas and areas with the highest risk of contamination allows the optimization of water protection zones, appropriate and prudent management of water sources, and a foundation for planning the monitoring of water quality. Hazard map make it possible to identify land mismanagement and are together with risk map used for land use planning. In the study area, the strictest

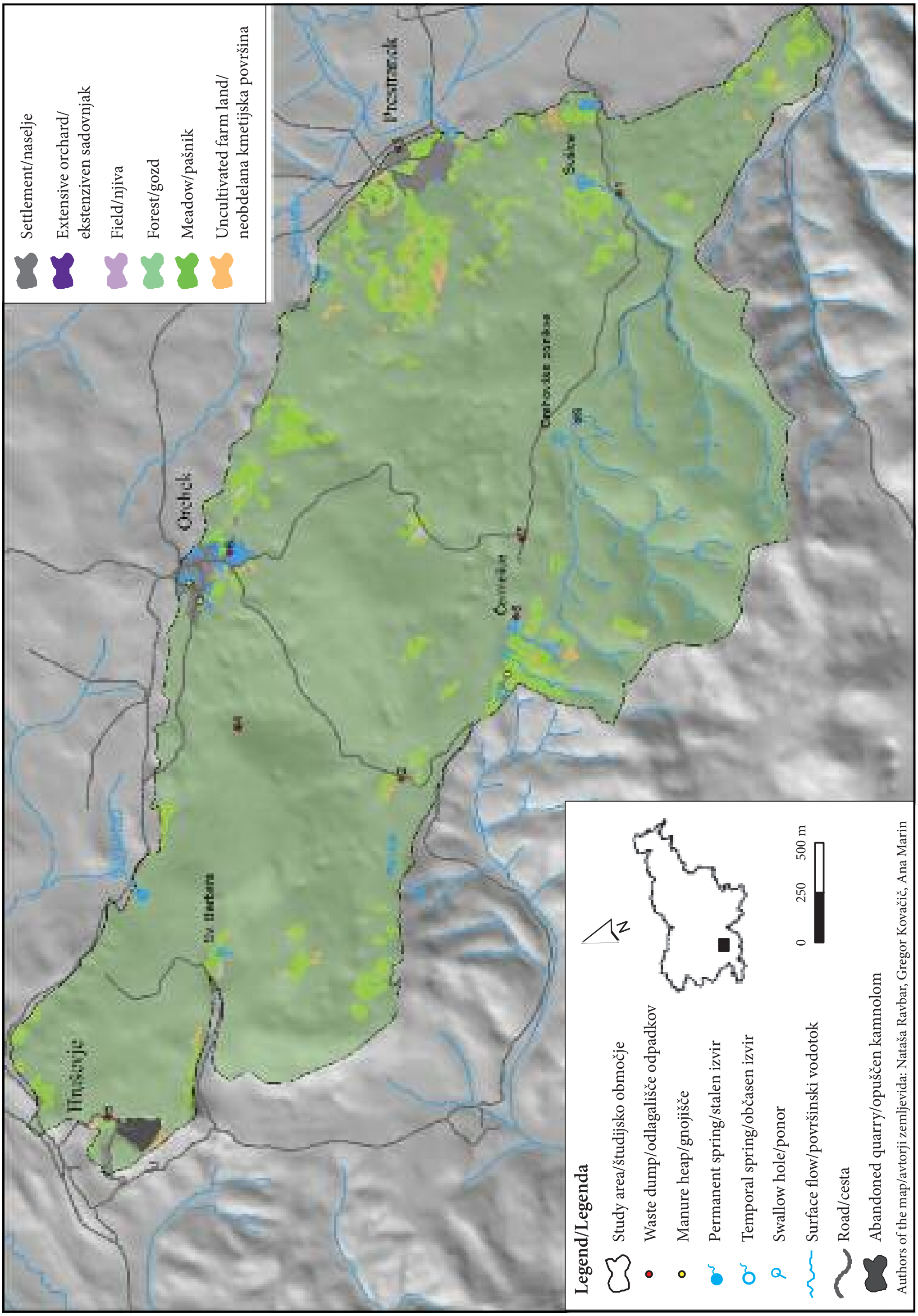

Figure 6: Unclassified hazard map of the Orehek karst.

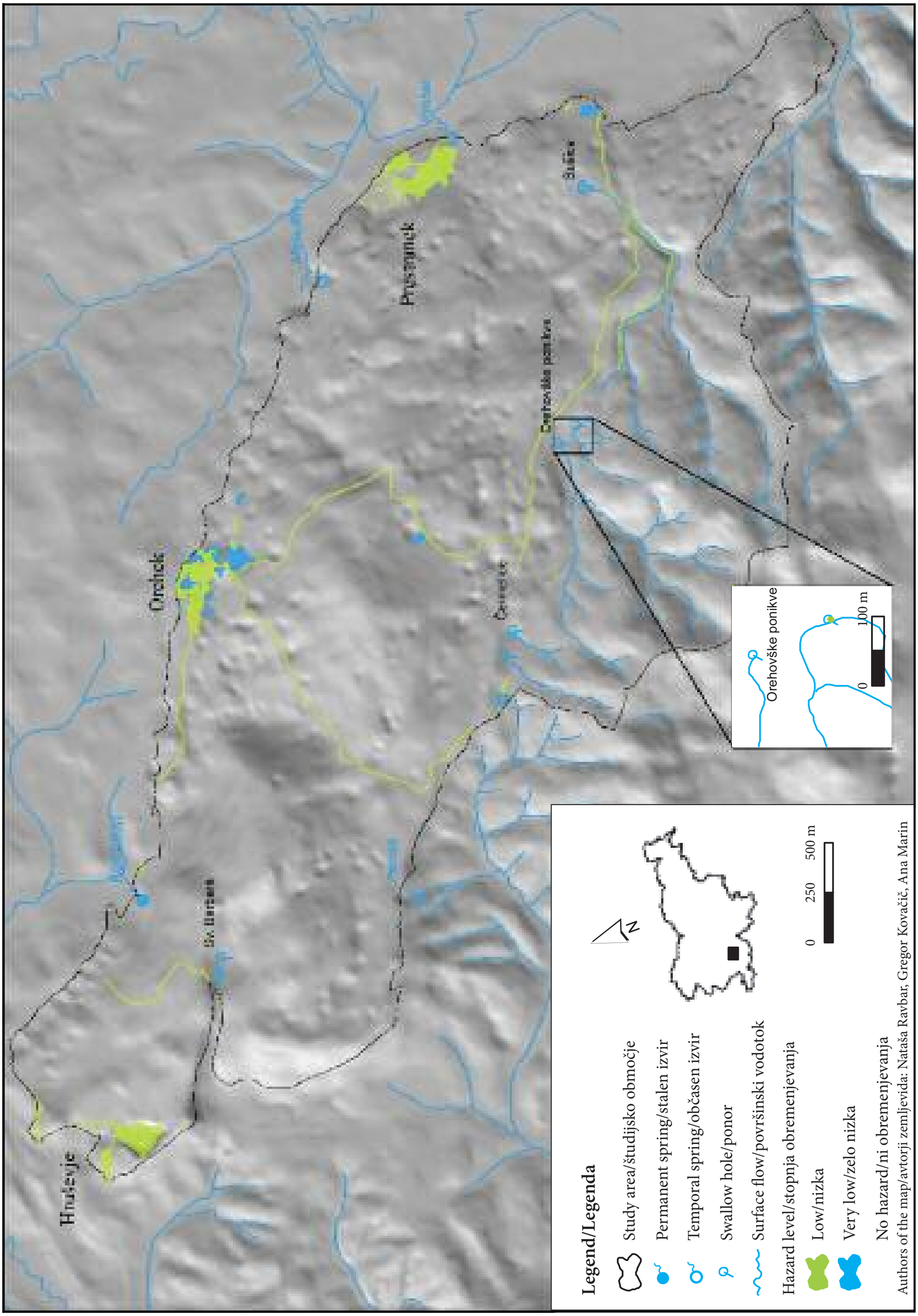

Figure 7: Classified hazard map of the Orehek karst.

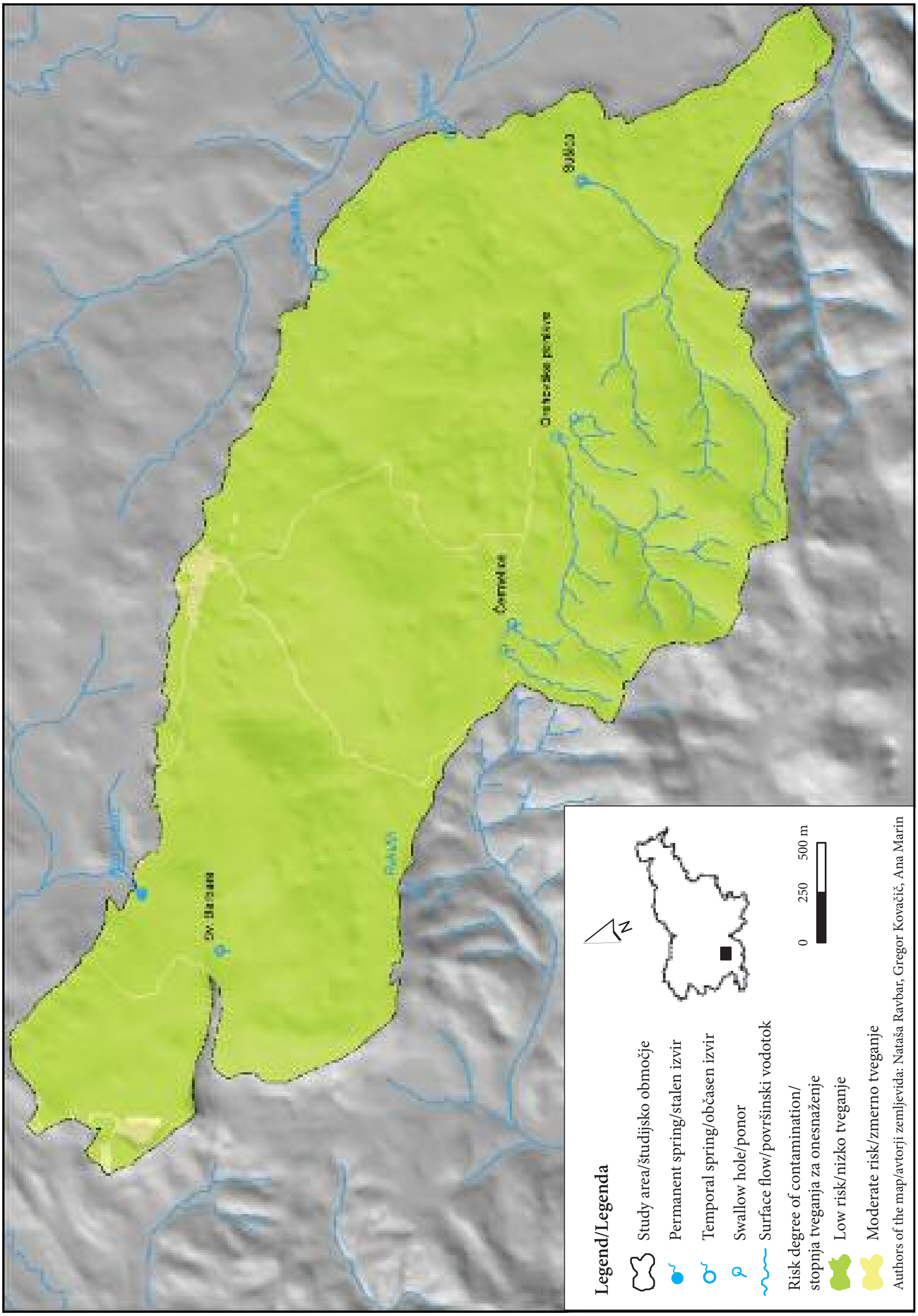

Figure 8: Risk to contamination map of the Korentan spring.

protection measures should apply to the most vulnerable areas, and the most harmful human activities should be properly sanitized or prohibited.

The concept of assessing vulnerability and risk offers a balance between protection on the one hand and spatial planning and economic interests on the other. It prevents adding potential sources of pollution in areas where pollution already reaches or even exceeds natural self-cleaning capacities and at the same time shows areas of the highest risk level that call for immediate action and rehabilitation. Studies as is the one presented here therefore provide a useful decision-making basis for national and local authorities responsible for spatial planning and land use.

The results of the survey in the Orehek area aquifer revealed that some parts (sinking rivers, excavation sites) demonstrate high intrinsic vulnerability and should be protected. On the other hand, a small number of actual and potential hazards in the catchment do not pose a serious risk to contamination of the Korentan spring. However, illegal dumps should be removed and sanitized, and manure heaps and sewer systems settlements regulated.

On bases of the currently established water protection zones (Habič et al. 1987; Odlok o varstvu krajevnih vodnih virov v Občini Postojna 1998) the area of the strictest protection extends over the springhead belt around the capture, while the rest of the Orehek karst together with the sinking rivers catchments (i.e. Outer zone) belong to the Inner protection zone with a strict protection regime. According to the source vulnerability map (Figure 5) the strictest protection regime needs to be introduced to areas of caves, excavation site and roads in the Korentan catchment, and to sinking Čermelice river, swallow holes and their surroundings. Major part of the Korentan catchment, including bare areas, caves, sinking rivers, swallow holes and their surroundings outside the Korentan catchment would belong to the Inner protection zone. Areas of dolines in the Korentan catchment and majority of the Orehek karst outside the Korentan catchment would belong to Outer protection zone.

Korentan spring, which had once been used for drinking water supply, would due to its satisfactory quantities in major part of the year be sensible to include into the water supply system of the Postojna municipality as a reserve water resource. However, suitable protection and proper land use planning should previously be ensured. Using the same method, numerous other small karst water sources should be revived and put into service of public drinking water supply systems in Slovenia.

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IZVLEČEK: Na območju Orehovškega krasa so bile s pomočjo t. i. Slovenske metode narejene karti naravne ranljivosti podzemne vode in kraškega izvira Korentan, karti obremenjevalcev in karta tveganja za onesnaženje. V ta namen so bili zbrani kartografski in drugi objavljeni podatki o geoloških, geomorfoloških, pedoloških, hidroloških ter meteoroloških značilnostih in opravljeno obsežno delo popisa manjkajočih geomorfoloških in pedoloških značilnosti. Pregledani in na terenu preverjeni so bili javno dostopni podatki o rabi tal in popisu prebivalstva, popisana so bila gnojišča in divja odlagališča odpadkov. Končne tematske karte so odličen pripomoček državnim in krajevnim organom pri varovanju vodnih virov in načrtovanju rabe prostora v njihovem zaledju. Predstavljena raziskava v zaledju konkretnega vodnega vira je obenem zgled dobre prakse obujanja v preteklosti opuščenih vodnih virov, ki lahko v prihodnje služijo kot nadomestni viri pitne vode v primeru prekomerne izrabe ali onesnaženja primarnih vodnih virov.

KLJUČNE BESEDE: pitna voda, kraški izvir, ocenjevanje ranljivosti, ocenjevanje tveganja za onesnaženje, kartiranje obremenjevalcev, varovanje voda, upravljanje voda.

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1 Uvod

Ključno vprašanje vodooskrbe v Sloveniji in drugod po svetu je, kako zagotoviti ustrezno kakovost in zadostno količino pitne vode. Zaradi vse večje onesnaženosti in hitrega zmanjševanja zalog v medzrnskih in drugih vodonosnikih pomen kraških vodnih virov narašča (Bakalowicz 2005; Ford in Williams 2007; Kresic 2009; Guo, Yuan in Qin 2010; Dar s sodelavci 2011). Prednost bolj izdatnih kraških izvirov so zadostne količine vode tudi ob nizkih vodostajih, vendar imajo takšni izviri velika prispevna zaledja, ki jih je težko učinkovito varovati pred onesnaženjem, zato je njihova kakovost pogosto slabša (Ravbar in Kovačič 2006).

Ker sodobna vodooskrba temelji na stalnih in izdatnih virih, so nekdanji viri, ki so sloneli na zajemanju skromnih kapacitet površinske, talne ali padavinske vode, popolnoma izgubili svoj pomen. V primeru onesnaženja pa lahko od enega samega vodnega vira odvisno območje ostane brez pitne vode oziroma je njena kakovost omejena in oskrba večjega območja motena.

Takšen je bil primer relativno dolgotrajnega onesnaženja kraškega izvira Malenščice ($Qs_{1971–2000}$ = 6,62 m^3/s; površina zaledja 726 km^2) koncem leta 2011 in v začetku leta 2012, ki je zajet za vodooskrbo prebivalcev občin Postojna, Pivka in delno Ilirska Bistrica (22.000 uporabnikov). Onesnaženje v izviru se je pojavilo zaradi izpiranja nakopičenega onesnaženja v vodnem valu, ki je nastopil po prvem nekoliko bolj intenzivnem padavinskem dogodku po dolgotrajnejšem obdobju brez padavin. Izvir je bil onesnažen in za vodooskrbo neprimeren skupaj 35 dni (20. 12.–31. 12. 2011; 12. 1.–3. 2. 2012), dokler na zajetju niso zagotovili dodatnega čiščenja. S tem pa je bila varna vodooskrba motena.

S povezavo različnih virov pitne vode v enoten sistem bi lahko omilili posledice takšnih dogodkov. Pri snovanju vodne oskrbe kaže v prihodnosti poleg obstoječega regionalnega vira v sistem vključiti še številne lokalne vire v povezavi s tradicionalno obliko vodne oskrbe. Zato je izdelava celostne strategije vodooskrbe na nacionalni ravni, ki bi zajemala varovanje in upravljanje vodnih virov ter ukrepanje ob izrednih dogodkih, nujno potrebna.

V primeru onesnaženja izvira Malenščica bi nemoteno pokritje najnujnejših potreb po čisti pitni vodi lahko zagotovila vključitev rezervnih vodnih virov. V postonjski vodovod je v preteklosti že bil zajet za vodooskrbo, leta 1972 pa opuščen, kraški izvir Orehovškega krasa Korentan (Petrič in Šebela 2004; Kovačič in Petrič 2007). Glede na ocenjeno razpoložljivo količino vode in njeno kakovost ter relativno neobremenjenost Orehovškega krasa bi Korentan lahko bil nadomestni vir za vodooskrbo. Izvir je zavarovan na osnovi lokalnega odloka (Odlok o varstvu krajevnih vodnih virov v Občini Postojna 1998), toda da bi učinkovito obvarovali kakovost vodnih zalog Orehovškega krasa, je najpomembneje prepoznavanje najbolj ranljivih območij, obstoječih obremenjevalcev in predlaganje najbolj primerne rabe tal. Zato smo v študiji, ki jo predstavljamo, ocenili naravno ranljivost podzemne vode Orehovškega krasa in izvira Korentan, popisali obstoječe obremenjevalce ter za Korentan izdelali karto tveganja za onesnaženje.

Prikazani izsledki predstavljajo dobro podlago pri oblikovanju temeljnih načrtov za previdno upravljanje z vodnimi viri v podobnih primerih v prihodnje, da bomo sebi in bodočim generacijam omogočili nadaljnjo nemoteno oskrbo s pitno vodo in ohranjali zadostne količine kakovostnih vodnih zalog.

2 Preučevano območje

Orehovški kras je z vseh strani jasno omejen plitev kraški vodonosnik, ki leži severozahodno od doline Pivke (Slika 1). Njegova površina je približno 10 km^2. Nekoliko vzdignjeno vršno sleme doseže višino 725 m, okolica leži na višinah 545–600 m. Vodonosnik je oblikovan v antiklinali krednih in paleocenskih apnencev (Slika 2), ki so na jugozahodu delno narinjeni na eocenske flišne kamnine, ki vodonosnik sicer obkrožajo z vseh strani (Gospodarič, Habe in Habič 1970; Petrič in Šebela 2004). Orehovški kras je dobro zakrasel s številnimi vrtačami (461) in 70 registriranimi jamami v Slovenskem jamskem katastru (2012). V severnem delu karbonatne kamnine prekriva tanek sloj rendzine, v južnem delu pa prevladujejo različno globoke rjave pokarbonatne prsti. Orehovški kras leži na meji med zmerno celinskim in zalednim submediteranskim podnebjem; povprečna letna količina padavin je 1.600 mm.

Na jugozahodu vodonosnik napajajo tudi številne manjše ponikalnice (Čermelice, Orehovške ponikve). Na severovzhodnem robu zelo slabo prepustne flišne kamnine predstavljajo hidrološko pregrado preučevanemu vodonosniku. Vodonosnik se prazni skozi dva občasna izvira (Poliček in Mrzla jama) in stalni izvir Korentan. Sledilni poizkus je ob visokih vodah dokazal povezavo južnega dela vodonosnika in ponora Orehovške ponikve z izvirom Poliček. Ob nizkih vodah vode iz južnega dela vodonosnika podzemeljsko odtekajo proti vzhodu v reko Pivko (ni prikazano na sliki 2) (Gospodarič, Habe in Habič 1970). Sledilni poizkus, opravljen ob srednjih vodah, je dokazal podzemeljsko zvezo ponorov Čermelice z izvirom Korentan. Hitrost podzemeljskega toka je bila ocenjena na 25 m/h, v izvir je prišlo 71 % injiciranega sledila (Schulte 1994).

Glavni iztok iz vodonosnika orehovškega krasa je izvir Korentan, ki je tipičen kraški izvir, s hitrim in izrazitim odzivom na padavinske dogodke. Pretok izvira se giblje od nekaj l/s do 3 m^3/s, povprečni pretok je 0,2 m^3/s. Na osnovi rezultatov sledilnega poizkusa in metode vodne bilance je bilo zaledje izvira ocenjeno na 6 km^2 (upoštevajoč tudi ne-kraški del zaledja) (Schulte 1994; Petrič in Šebela 2004; Jemcov in Petrič 2009; Kogovšek in Petrič 2012).

Slika 1: Panoramska slika Orehovškega krasa.
Glej angleški del prispevka.

Slika 2: Hidrogeološke in geomorfološke razmere Orehovškega krasa in okolice (prirejeno po Buser, Grad in Pleničar 1967; Pleničar 1970; Gospodarič, Habe in Habič 1970; Petrič in Šebela 2004).
Glej angleški del prispevka.

3 Metodologija

Za učinkovito varovanje najbolj občutljivih območij kraških vodonosnikov se v nekaterih evropskih državah pri določanju vodovarstvenih pasov uporablja koncept ocenjevanja ranljivosti, pri načrtovanju rabe prostora pa v ospredje vse bolj stopa ocenjevanje tveganja za onesnaženje (Zwahlen 2004; Ravbar 2007; Goldscheider 2010). Evropskim smernicam najbolj celostno sledi pri nas razviti Slovenski pristop (Ravbar in Goldscheider 2007), ki je uporabljen v pričujoči študiji. Metoda vključuje ocenjevanje ranljivosti in stopnjo obremenjevanja kraške podtalnice ali vodnega vira. Ti dve oceni sta podlaga za izdelavo ocene tveganja za onesnaženje podtalnice ali vodnega vira.

Ocenjevanje naravne ranljivosti upošteva geološke, geomorfološke, pedološke, hidrogeološke in meteorološke značilnosti kraškega sistema in je neodvisno od lastnosti in obnašanja posameznih onesnaževal (Preglednica 1, glej tudi sliko 3). Glede na namen sta na voljo dve vrsti ocenjevanja ranljivosti: za podzemno vodo in za vodni vir. Ocenjevanje ranljivosti podzemne vode upošteva parametre, ki nadzorujejo tok infiltrirane vode vse od površja do gladine podzemne vode. Pri tem so pomembni kazalniki prepustnost in debelina prsti in kamnin, ki sestavljajo nezasičeno cono, koncentracija odtoka v podzemlje, na katero vplivata topografija, rastlinski pokrov ter razporeditev in intenziteta padavin. Z dodatnim parametrom, ki upošteva značilnosti pretakanja voda v zasičeni coni, je mogoče oceniti ranljivost vodnega vira (Slika 3).

Slika 3: Konceptualni model kraškega vodonosnika in parametri, ki vplivajo na ranljivost podzemne vode ali vodnega vira (prirejeno po Andreo, Ravbar in Vías 2009).
Glej angleški del prispevka.

Ocena zaščitne funkcije slojev nad kraško podtalnico vodonosnika Orehovškega krasa temelji na podatkih geoloških in pedoloških kart in je bila preverjena na terenu s pomočjo geološkega in geomorfološkega kartiranja ter z merjenjem debeline prsti s pomočjo ročnega svedra. Dodatne informacije so bile pridobljene s topografskih kart, digitalnih ortofoto posnetkov in jamskega katastra Slovenije (SCC 2012). Debelina nezasičene cone je bila določena z razliko med mrežo točk digitalnega modela višin in ocenjenih gladin podtalnice (na podlagi nadmorskih višin ponorov in izvirov).

Značilnosti infiltracije in koncentracije toka smo ocenili s pomočjo digitalnega modela višin, topografskih kart in kart rabe tal iz leta 2012 (Internet 1). Tokovne procese smo ocenili s pomočjo geoloških podatkov in neposrednih terenskih opazovanj. Za določitev značilnosti padavinskega režima in napajanja smo uporabili letne in dnevne podatke (obdobje 1961–2010) o padavinah z meteorološke postaje Postojna (EARS 2010).

Značilnosti toka v zasičeni coni kraškega vodonosnika smo ocenili na osnovi geoloških in geomorfoloških razmer, analize hidrograma dnevnih pretokov izvira Korentan v hidrološkem letu 2004 (23. 9. 2003–31. 8. 2004)

Preglednica 1: Podatki, potrebni za ocenjevanje naravne ranljivosti podzemne vode Orehovškega krasa in izvira Korentan.

	podatki		
KRAŠKA NEZASIČENA CONA	debelina prsti struktura prsti tekstura prsti prepustnost podtalja debelina podtalja debelina nezasičene cone razpokanost razvoj epikrasa/kraške geomorfološke oblike zaprtost vodonosnika	ranljivost izvira Korentan	ranljivost podzemne vode Orehovškega krasa
NAČINI NAPAJANJA	koncentracija toka naklon površja raba tal/vegetacijski pokrov avtogeno napajanje alogeno napajanje hidrološka spremenljivost		
KRAŠKA ZASIČENA CONA	prisotnost mreže aktivnih kraških kanalov hidrološke značilnosti izvira interpretacija sledilnih poizkusov		

(Petrič in Šebela 2004), hidrološke bilance v obdobju 1961–2010 in interpretacije rezultatov sledilnega poskusa (Schulte 1994). Dodatne informacije smo pridobili iz baze jamskega katastra Slovenije (SCC 2012).

Karta ranljivosti ni vedno zadovoljivo orodje za pravilno načrtovanje rabe prostora, ker ne pokaže že dosežene stopnje obremenjenosti kraškega vodonosnika. Zato je bilo v okviru te študije izvedeno tudi ocenjevanje obremenjevalcev. Cilj takšnega kartiranja je identifikacija ter prikaz lokacij različnih vrst dejavnosti, ki predstavljajo nevarnost za kakovost kraške podtalnice. Ocena obremenjevanja zajema vrsto, strupenost in količino onesnaževala, kot tudi verjetnost, da bo do onesnaženja prišlo (De Ketelaere s sodelavci 2004).

Informacije za kartiranje obremenjevalcev Orehovškega krasa smo pridobili s topografskih kart, podatkovne baze rabe tal (Internet 1) in neposrednim terenskim opazovanjem. Pri kartiranju obremenjevalcev je za vsakega onesnaževalca predvidena določena vrednost glede na kvalitativno primerjavo potencialne škode (toksičnost substanc, njihova topnost in mobilnost), za primerjavo znotraj ene vrste obremenjevalcev pa se predvideva proces razvrščanja glede na stopnjo strupenosti substanc, čas izpostavljanja obremenjevanju ali glede na količino oziroma velikost onesnaževalca. Upošteva se še verjetnost onesnaženja, na kar vplivajo tehnični status, stopnja vzdrževanja, varnostne razmere in druge okoliščine. Lokacije in značilnosti potencialnih in dejanskih virov onesnaženja smo preverili in pridobili s terenskim delom.

Ko smo karto ranljivosti vodnega vira Korentan dopolnili s kartami obremenjevalcev, smo lahko ocenili tveganje tega izvira za onesnaženje. Na ta način smo celostno ovrednotili dosedanje človekove vplive in identificirali najbolj nevarna območja, ki vplivajo na kakovost potencialno uporabnega vodnega vira pri Postojni.

Za obdelavo podatkov, ocenjevanje posameznih parametrov in kartiranje smo uporabili programsko orodje ArcGIS 9.3.

4 Rezultati

4.1 Karta ranljivosti

Karta ranljivosti kraške podtalnice, ki ima namen varovati celotno telo podzemne vode (Slika 4), kaže, da je zgolj 4,4 % zaledja izredno ranljivega. To so območja jam, območja brez rastlinskega pokrova in prsti, kot so izkopi in ceste, ter območja ponikalnic, ponorov in njihova neposredna bližina. Večino območja označuje visoka ranljivost (81,3 %). Srednja ranljivost je značilna za 12,9 % območja; to so vrtače in nekateri deli porečij ponikalnic. Vrtače so ovrednotene z nižjo stopnjo ranljivosti kot ostali kraški predeli predvsem zaradi precejšnje debeline zaščitne plasti v njihovih dneh (t. j. > 1 m prsti). Območja nizke ranljivosti se raztezajo na 1,4 % površja v bolj oddaljenih delih porečij ponikalnic na neprepustnih kamninah. Stopnja ranljivosti je na nekraških območjih odvisna predvsem od vegetacijskega pokrova in naklona pobočij.

Slika 4: Ranljivost podzemne vode Orehovškega krasa.
Glej angleški del prispevka.

Za kartiranje ranljivosti vodnega vira (varovanje posameznega izvira, to je Korentan) je bilo območje Orehovškega kraškega vodonosnika razdeljeno v notranjo in zunanjo cono. Razdelitev je bila narejena na osnovi geoloških in geomorfoloških značilnosti, rezultatov sledilnih poizkusov in hidrodinamičnih lastnosti izvira Korentan (glej reference zgoraj). Notranja cona je območje, ki vedno prispeva vodo v preučevani izvir in je neposredno povezano z izvirom oziroma stalno dovaja vodo v izvir. Zunanja cona obsega preostali del vodonosnika, od koder voda ne odteka v preučevani izvir (glej sliko 2). Stopnje ranljivosti so zato v zunanji coni nižje kot v notranji.

Na karti ranljivosti Korentana (Slika 5) območja z visoko stopnjo ranljivosti zavzemajo 1,6 % površin. To so območja jam, izkopov in cest v zaledju Korentana ter ponikalnica Čermelice, ponori in njihova okolica. Srednja ranljivost je določena za 54,2 % preučevanega območja, gre za večji del zaledja Korentana ter gole površine, jame, ponikalnice, ponore in njihovo okolico, ki se nahajajo zunaj neposrednega hidrografskega zaledja Korentana. Območja z nizko stopnjo ranljivosti se raztezajo na 44,2 % območja in ustrezajo vrtačam ter večini Orehovškega krasa zunaj hidrografskega zaledja Korentana.

Karta ranljivosti vodnega vira se lahko uporabi kot osnova za izdelavo vodovarstvenih območij.

Slika 5: Ranljivost izvira Korentan.
Glej angleški del prispevka.

4.2. Karta obremenjevalcev

Večji del, to je 92% Orehovškega krasa prekriva gozd (prevladuje bukev). Kmetijska dejavnost je majhna in omejena na okolico naselij Prestranek, Hruševje in Orehek, ki ležijo na robu vodonosnika Orehovškega krasa. V okolici naselij je nekaj njiv in ekstenzivnih sadovnjakov. Okoli 6% območja prekrivajo travniki in pašniki (Internet 1).

V Hruševju in Prestranku zgolj nekaj stanovanjskih hiš leži znotraj vodonosnika Orehovškega krasa, medtem ko približno polovica Orehka leži znotraj njega. Glede na popis prebivalstva 2011 živi na območju približno 150 ljudi (Internet 2). Naselja nimajo urejene kanalizacije. Vodonosnik prečijo lokalne makadamske ceste, ki jih v večini uporabljajo kmetje in gozdarji, prometni tok je zanemarljiv. V smislu varovanja vode sta neintenzivno kmetijstvo in gosta poraščenost z gozdom zelo ugodna. Kljub temu obstoji nekaj dejanskih in potencialnih točkovnih in površinskih virov onesnaženja na vodonosniku.

V bližini Hruševja je opuščen kamnolom, ki se občasno uporablja za odlaganje predvsem organskih odpadkov. V Orehku smo evidentirali dve odprti gnojišči, eno večje in nezavarovano gnojišče je blizu kmetije, ki leži 100 m pred ponorom Čermelice. Izcedne vode iz gnojišča odtekajo po manjšem odtočnem jarku neposredno v ponor in ogrožajo kakovost izvira Korentan.

Terenska raziskava v letu 2011 je pokazala, da kakovost Orehovškega kraškega vodonosnika ogroža devet divjih odlagališč odpadkov. Tri izmed njih ležijo v vrtačah (št. 1, 2, in 8 na sliki 6), dve v breznih (št. 4 in 7), eno pa leži v ponorni jami Orehovške ponikve (št. 9). Slednje resno ogroža kakovost izvira Poliček, vendar sodeč po znanih dejstvih, ne ogroža izvira Korentan. Število divjih odlagališč odpadkov se je v zadnjih letih zmanjšalo; v letu 2002 smo jih evidentirali 34. Večina od tedaj aktivnih odlagališč je sedaj saniranih ali opuščenih.

Neklasificirana karta obremenjevalcev (Slika 6) prikazuje opisane dejanske in potencialne vire onesnaženja, medtem ko klasificirana karta obremenjevalcev (Slika 7) prikazuje možen vpliv človekovih dejavnosti na vode.

Slika 7 kaže, da je stopnja obremenitve na proučevanem območju nizka (2,3 %) ali zelo nizka (0,4 %). Naselja brez kanalizacije, ceste, zapuščen kamnolom, divja odlagališča odpadkov in odprta gnojišča predstavljajo nizko stopnjo obremenjevanja, njive in sadovnjaki pa zelo nizko stopnjo obremenjevanja. Večji del območja, 97,3 %, ni izpostavljen obremenjevanju.

Slika 6: Neklasificirana karta obremenjevalcev Orehovškega krasa.
Glej angleški del prispevka.

Slika 7: Klasificirana karta obremenjevalcev Orehovškega krasa.
Glej angleški del prispevka.

4.3 Karta tveganja za onesnaženje

Karta tveganja za onesnaženje se pridobi s kombinacijo ocene ranljivosti in obremenjevanja. Na ta način lahko celostno ovrednotimo dosedanje človekove vplive in določimo območja z neustreznim upravljanjem, reorganiziramo rabo prostora in zasnujemo boljšo prakso v prihodnjem načrtovanju, podlago za različne presoje vplivov na okolje ter lažje predvidevamo posledice in škode (ekološke in materialne) ob različnih onesnaženjih.

V preučevanem območju je ocena stopnje tveganja za onesnaženje močno odvisna od stopnje obremenjevanja in njegove razporeditve. Večina hidrografskega zaledja (98,5 %) je podvržena nizki stopnji tveganja, samo območja poselitve, cest, divjih odlagališč odpadkov in izkopov predstavljajo srednjo stopnjo tveganja za onesnaženje, ki obsega 1,5 % preučevanega območja (Slika 8).

Slika 8: Karta tveganja za onesnaženje izvira Korentan.
Glej angleški del prispevka.

5 Sklep

Ta študija kaže, na kakšen način je potrebno vrednotiti kraške vodne vire nekega območja, ki v primeru onesnaženja regionalnega vira pitne vode lahko služijo kot nadomestni vodni viri. S pomočjo kartografskih in drugih objavljenih podatkov ter terenskega dela je potrebno oceniti njihovo naravno ranljivost, stopnjo obremenjevanja in izdelati oceno tveganja za onesnaženje, rezultate pa prikazati na razumljivih tematskih kartah. Te karte je zelo enostavno uporabljati za načrtovanje različnih dejavnosti v zaledjih kraških vodnih virov.

Oceno naravne ranljivosti je mogoče preoblikovati v vodovarstvene pasove. Identifikacija najranljivejših območij in območij največjega tveganja za onesnaženje podaja optimizacijo vodovarstvenih pasov, primerno in previdno upravljanje vodnih virov ter podlago za načrtovanje monitoringa kakovosti podzemne vode. Karta obremenjevalcev omogoča identifikacijo neustreznega upravljanja in je skupaj s karto tveganja za onesnaženje uporabna za prostorsko načrtovanje. Na proučevanem območju naj bi na najranljivejših območjih veljali najstrožji ukrepi varovanja, najbolj škodljive človekove dejavnosti naj bi bile sanirane oziroma prepovedane.

Koncept ocenjevanja ranljivosti in tveganja ponuja ravnotežje med varovanjem na eni ter prostorskim načrtovanjem in ekonomskimi interesi na drugi strani. Preprečuje postavitev potencialnih onesnaževalcev na območja, kjer obremenjevanje že dosega ali celo presega naravne samočistilne sposobnosti in hkrati opozarja na območja z najvišjo stopnjo tveganja, ki terjajo takojšnje ukrepanje in sanacijo. Študije, kot je predstavljena, so tako za državne in krajevne organe, odgovorne pri načrtovanju in odločanju o rabi prostora, koristna osnova pri njihovih odločitvah.

Rezultati raziskave na območju vodonosnika Orehovškega krasa so pokazali, da nekatera območja (ponikalnice, izkopi) izkazujejo veliko naravno ranljivost in morajo biti zavarovana. Maloštevilni dejanski in potencialni obremenjevalci v zaledju izvira Korentan ne predstavljajo pomembnejšega tveganja za njegovo onesnaženje. Vendar pa morajo biti vsa divja odlagališča odpadkov odstranjena in sanirana, gnojišča ter kanalizacijski sistemi v naseljih pa urejeni.

Po trenutno uveljavljenih vodovarstvenih območjih (Habič s sodelavci 1987; Odlok o varstvu krajevnih vodnih virov v Občini Postojna 1998) območje najstrožjega varovanja obsega najožji pas okoli zajetja, celotno območje Orehovškega krasa s prispevnimi območji ponikalnic (t. i. zunanja cona) pa v ožji varstveni pas s strogim režimom varovanja. Glede na rezultate karte ranljivosti Korentana (Slika 4) bi bilo potrebno strogo varovati območja jam, izkopov in cest v zaledju Korentana ter območje ponikalnice Čermelice, ponorov in njihove okolice. Večji del zaledja Korentana, vključno z golimi površinami, jamami, ponikalnicami, ponori in njihovo okolico, ki se nahajajo zunaj neposrednega hidrografskega zaledja Korentana, bi pripadlo ožjemu območju varovanja, območja vrtač ter območja zunaj hidrografskega zaledja Korentana pa v širše varovalno območje.

Korentan, ki je nekoč že bil zajet za vodooskrbo, bi bilo zaradi razmeroma zadovoljivih količin vode v večjem delu leta bilo kot nadomestni vodni vir smiselno vključiti v sistem vodne oskrbe občine Postojna. Vendar je predhodno potrebno na predlagani način zagotoviti primerno zavarovanje vodnega vira ter načrtovanje rabe prostora. Na podoben način bi bilo potrebno oživiti tudi številne manjše kraške vodne vire ter jih vključiti v sistem javne vodooskrbe v Sloveniji.

6 Zahvala

Študija je prispevek k projektu UNESCO/IUGS IGCP 513 »Global Study of Karst Aquifers and Water Resources«.

7 Literatura

Glej angleški del prispevka.