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PRIMENA METODA ZA OCENU RANJIVOSTI PODZEMNIH VODA U ZAŠTITI VODNIH RESURSA SEVERNOG DELA OZRENA I DEVICE

APPLICATION OF GROUNDWATER VULNERABILITY ASSESSMENT METHODS IN THE PROTECTION OF WATER RESOURCES OF NORTHERN PARTS OF OZREN AND DEVICA MOUNTAINS

APSTRAKT

U zaštiti vodnih resursa se u novije vreme sve više koriste metode za ocenu ranjivosti podzemnih voda. Karte dobijene primenom ovih metoda imaju značajnu primenu u zaštiti podzemnih voda predela izuzetnih prirodnih odlika u kojima razvoj turizma može ugroziti prirodne vrednosti. U radu je prikazana primena COP metode za ocenu ranjivosti podzemnih voda severnog dela Ozrena i Device u istočnoj Srbiji. Pomenuto istražno područje je od posebnog interesa zbog sve većeg turističkog razvoja Sokobanje. COP metoda je odabrana jer je metoda koja je kreirana u skladu sa „Evropskim pristupom" (projekat COST 620) kojim su date smernice za ocenu ranjivosti karstnih podzemnih voda. Upravo je i najveći deo istražnog prostora izgrađen od karbonatnih stena u kojima postoji karstna izdan. Prilikom primene metode analizirani su različiti parametri kojima je procenjena zaštitna uloga slojeva u nadizdanskoj zoni (O faktor), način infiltracije (C faktor), kao i veličina i intenzitet padavina (P faktor). Preklapanjem ovih karata dobijena je COP karta ranjivosti podzemnih voda koja nam izdvaja područja gde su podzemne vode najranjivije i gde posebno treba posvetiti pažnju merama zaštite životne sredine. Dobijena karta se može iskoristiti kao podloga u prostornom planiranju čime se u budućnosti mogu sprečiti aktivnosti koje bi mogli da ugroze vodne resurse na ovom području.

Ključne reči: ranjivost podzemnih voda, karta ranjivosti, karstna izdan, COP metoda.

ABSTRACT

Vulnerability assessment methods are more and more used as a tool for water resource protection. Vulnerability maps can be used for groundwater protection of natural areas of significant values. The paper presents implementation of COP method for groundwater vulnerability assessment of northern parts of Ozren and Devica Mountains in eastern Serbia. This area is of particular interest as a result of touristic development od Sokobanja spa. The COP method is chosen because it is aligned with "European approach" (project COST 620) where guidelines for vulnerability assessment of karst groundwater are given. The biggest part of research area is built of carbonate rock with predominant karst porosity. Different parameters are analysed to create a base for evaluation of protection function of unsaturated zone (O factor), infiltration conditions (C factor) and amount and intensity of precipitation (P factor). COP groundwater vulnerability map was created by overlying of these parameters. Produced map shows where groundwater is mostly vulnerable and where special nature protection measures are to be implemented. Obtained map can be used as a tool for spatial planning for preventing activities which can endanger water resources in this area.

Key words: groundwater vulnerability, vulnerability map, karst aquifer, COP method.

UVOD

Karstne izdani karakteriše mogućnost akumuliranja značajnih rezervi kvalitetnih podzemnih voda. U Republici Srbiji, ove izdani zauzimaju značajno mesto u obezbeđivanju potrebnih količina kvalitetnih voda za potrebe vodosnabdevanja stanovništva.

Ograničavajući faktor korišćenja voda karstnih izdani je njihova velika ranjivost sa površine terena. Karbonatne stene odlikuje prisustvo pukotina, kanala i kaverni, koje omogućava brzu infiltraciju i smanjuje mogućnost razgradnje zagađujućih supstanci, i na taj način pospešuje prodiranje zagađenja do izdanskih voda.

Imajući u vidu značaj karstnih izdanskih voda, neophodno je preduzeti odgovarajuće mere zaštite

INTRODUCTION

Karst aquifers are characterized by the possibility of accumulating significant reserves of quality groundwater. These aquifers are very common in Serbia and are particularly important in securing of necessary amounts of quality water for community water supply.

High vulnerability of karst water from the terrain surface is limiting factor for extensive use. Carbonate rocks are distinguished by the presence of cracks, canals and caverns, which allow rapid surface water infiltration and fast transport of contaminants to the aquifer which reduces the possibility of contaminant degradation.

Bearing in mind the importance of karst aquifer water, it is necessary to take appropriate measures to protect them. One of the basic steps in the protection

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istih. Jedan od osnovnih koraka u zaštiti podzemnih voda predstavljaju ocena ranjivosti i karte ranjivosti podzemnih voda (Živanović 2011). Koncept ocene ranjivosti podzemnih voda prvi put je predstavljen 60-tih godina XX veka od strane francuskog istraživača Margat (Vrba i Zaporozec 1994). Ideja je bila da se opiše stepen ranjivosti na kontaminaciju podzemnih voda kao rezultat prirodnih karakteristika sredine. Primenom metoda za ocenu ranjivosti dobijaju se karte ranjivosti podzemnih voda koje u zavisnosti od geoloških, pedoloških, geomorfoloških, hidrogeoloških i drugih uslova određuju koliko je lako ili teško za neku zagađujuću supstancu da prodre sa površine terena do podzemnih voda (Živanović 2012). Na kartama je predstavljeni prostor klasifikovan i obojen prema stepenu ranjivosti čime se lakše ističe različit potencijal da priroda zaštiti podzemne vode od uticaja sa površine terena (Foster 2002).

OPIS METODE

Prilikom izbora metode za ocenu ranjivosti podzemnih voda, neophodno je sagledati geološke, hidrološke i hidrogeološke uslove sredine i izabrati onu metodu koja je najbolje prilagođena konkretnim uslovima. Analizom parametara koji mogu imati uticaj na ranjivost podzemnih voda, kao i obima dostupnih podataka, ali i činjenice da najveći deo područja istraživanja pripada karstnoj izdani, izabrana je COP metoda (Vias 2005), kao najbolje prilagođena metoda. Ova metoda zasniva se na definisanju zaštitne funkcije nadizdanske zone u odnosu na difuznu infiltraciju, pri čemu se u obzir uzima i mogućnost zaobilaženja zaštitne funkcije koju pruža nadizdanska zona, punktualnom infiltracijom preko ponora, ali i poniranjem duž ponirućih tokova (Vias 2005).

COP metoda je razvijena na hidrogeološkom odseku Univerziteta u Malagi (Vias 2005), u okviru projekta COST 620 (Zwahlen 2004). Danas predstavlja jednu od najdetaljnijih i najobuhvatnijih metoda za ocenu ranjivosti karstnih izdanskih voda. Može se primeniti za različite klimatske uslove i za različite karbonatne izdani, ali i za različite stepene istraženosti terena. Kao i što je preporučeno Evropskim pristupom za ocenu opšte ranjivosti karstnih podzemnih voda (***Slika 1***), COP metoda se bazira na tri faktora (Vias 2005):

- ***C****oncentration of flow* – Koncentrisanost toka;
- ***O****verying layers* – Povlatni slojevi, i
- ***P****recipitation* – Padavine.

Pri formiranju karte ranjivosti prvi korak je određivanje O faktora, kojim se definiše zaštitna funkcija nadizdanske zone i mogućnost nadizdanskih slojeva da smanje kontaminacioni During the creation the vulnerability maps, the first step is the assessment the O factor. This factor defines the protective function of the unsaturated zone and the ability of the upper potencijal. C faktor se smatra korekcionim koeficijentom faktora O, jer pokazuje koliko je voda sa

of groundwater is the vulnerability assessment and preparation of groundwater vulnerability maps (Živanović 2011). The concept of the groundwater vulnerability assessment was first introduced in the 1960s by the French researcher Margat (Vrba and Zaporozec 1994). The idea was to describe the degree of vulnerability to contamination of groundwater as a result of the natural characteristics of the environment. Using vulnerability assessment methods, groundwater vulnerability maps are obtained, which depending on geological, pedological, geomorphological, hydrogeological and other conditions, determine how easy or difficult for a contaminant is to penetrate from the terrain surface to the groundwater (Živanović 2012). Area presented on these maps is classified and coloured according to the vulnerability degree, which makes it easier to highlight the different potential of nature to protect groundwater from the terrain surface (Foster 2002).

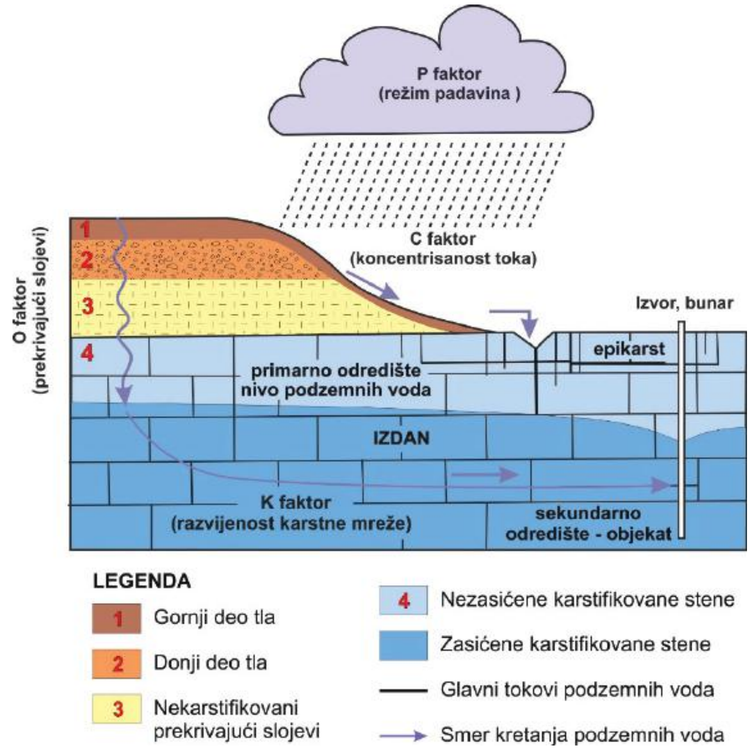
DESCRIPTION OF THE METHOD

When method for assessing the groundwater vulnerability is being selected, it is necessary to consider the geological, hydrological and hydrogeological conditions of the environment and to choose the method that is best adapted to the concrete conditions. Analysing the parameters that can influence the vulnerability of groundwater, the amount of available data, but also the fact that karst aquifer is mostly present in the research area, COP method was selected (Vias 2005). This method is based on the assessment of the protective function of the unsaturated zone in relation to the diffuse infiltration, taking into account the possibility of avoiding of this protective function in the area of ponors or sinking streams where punctual infiltration occur (Vias 2005).

The COP method was developed at the hydrogeological department of the University of Malaga (Vias 2005), within the COST 620 project (Zwahlen 2004). Today it is one of the most detailed and comprehensive method for assessing the vulnerability of karst aquifers. It can be applied to different climatic conditions for different carbonate aquifers, but also for different levels of field research. As recommended in the European approach for assessment of the intrinsic vulnerability of karst groundwater (***Figure 1***), the COP method is based on three factors (Vias 2005):

- ***C****oncentration of flow*,
- ***O****verying layers*,
- ***P****recipitation*.

During the creation the vulnerability maps, the first step is the assessment the O factor. This factor defines the protective function of the unsaturated zone and the ability of the upper layers to reduce the contamination potential. The C factor is considered to be the correction factor of the factor O, as it reflect the possibility for water to travel through specific karst features at the surface and to bypass the protective role



Slika 1. Evropski pristup (konceptualni model) za ocenu ranjivosti podzemnih voda baziran na konceptualnom modelu „Ulaz – Putanja - Odredište" (Zwalen 2004, Živanović 2011)
Figure 1. European approach (conceptual model) for the assessment of vulnerability of groundwater based on the conceptual model origin-pathway-target (Zwalen 2004, Živanović 2011)

površine u mogućnosti da preko specifičnih karstnih oblika zaobiđe zaštitnu ulogu nadizdanske zone i da direktno dođe do izdanske zone. Posebno se razmatraju dva moguća geološka slučaja, tj. scenarija: slivno područje ponora ili ponirućeg toka (scenario 1) i ostatak područja (scenario 2). P faktor odražava količinu padavina uključujući ne samo sumu, već i intenzitet kiša.

TEST PODRUČJE

Područje istraživanja nalazi se u istočnoj Srbiji. Predstavljeno je severnim delovima karstnog masiva Ozrena i Device, koji čini deo jedinstvenog planinskog luka Karpato-balkanida. Ozren i Devica predstavljaju jedinstveni morfostrukturni kompleks koji se diže iznad dna okolnih tercijarnih basena (Zeremski 2002).

Ove terene odlikuje složena geološka građa stvarana od paleozoika do danas. Najstarije stene datiraju iz kambrijuma, dok su najmlađe predstavljene kvartarnim tvorevinama (***Slika 2***). Najveće rasprostranjenje imaju stene mezozojske starosti predstavljene u najvećoj meri slojevitim i bankovitim krečnjacima i dolomitima. Složenu geološku građu područja istraživanja uslovila su navlačenja sa zapada prema istoku (Poružnički rased), kojima su formirani brojni plikativni i rupturni strukturni elementi, posebno na Ozrenu, a manjim delom i na Devici.

Sa hidrogeološkog aspekta u granicama područja istraživanja mogu se izdvojiti različiti tipovi izdani, ali i

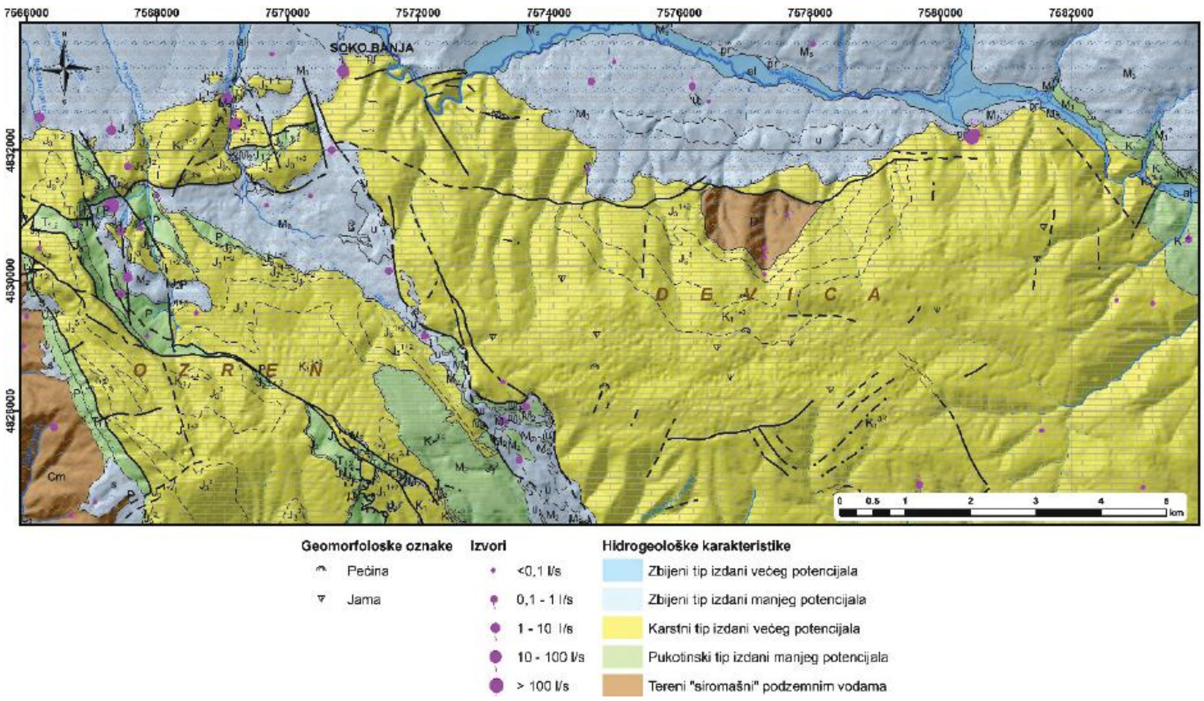
of the unsaturated zone. Two possible scenarios are assessed: the catchment area of the ponor or sinking stream (scenario 1) and the rest of the area (scenario 2). The P factor reflects the precipitation regime, including not only the sum, but also the rain intensity.

TEST AREA

The research area is located in eastern Serbia. It is presented by the northern parts of the karst massif of Ozren and Devica, which is the part of the unique Carpatho-Balkans Arch mountain. Ozren and Devica represent a unique morphostructural complex that rises above the bottom of the surrounding tertiary basins (Zeremski 2002).

These terrains are distinguished by the complex geological structure formed from the Paleozoic to the present. The oldest rocks date from the Cambrian, while the youngest from the Quaternary (***Figure 2***). Rocks from Mesozoic age are widely present at the surface and are presented mostly by layered and banked limestones and dolomites. The complex geological structure of the research area caused the overthrust from west to the east (Poruznica fault), which formed numerous plicative and rupture structural features, especially on Ozren, and to a lesser extent on Devica.

From the hydrogeological aspect within the boundaries of the research area, there are different types of aquifers, but also terrains with low permeable rocks, especially those dating the old Palaeozoic era. The intergranular



Slika 2. Hidrogeološka karta severnog dela masiva Ozrena i Device (Stojadinović 2018)
Figure 2. Hydrogeological map of the northern part of Ozren and Devica massif (Stojadinović 2018)

tereni „siromašni" podzemnim vodama, predstavljeni kompleksom stena staropaleozojske starosti. Zbijeni i pukotinski tip izdani nemaju značajnije rasprostranjenja, pa se samim tim ne karakterišu ni većim hidrogeološkim potencijalom. Najveće rasprostranjenje i najveći značaj ima karstna izdan formirana u krečnjacima i dolomitima mezozojske starosti. Pored znatnog rasprostranjenja na površini terena, karbonatni kompleks zaleže duboko ispod naslaga okolnih tercijarnih basena (Stojadinović 2018).

Najveći deo karstnih podzemnih voda potiče od infiltracije atmosferskih taloga i manjim delom od infiltracije voda površinskih tokova. Najintenzivnije prihranjivanje karstne izdani odvija se u terenima na ogolićenim krečnjačkim masivima, naročito ukoliko su razvijeni površinski karstni oblici, kakve su krečnjačke površi Ozrena i Device. Prihranjivanje izdani poniranjem vode iz površinskih tokova dokazano je na ponornici Tisovik i reci Izgari (Stevanović 1991).

Dreniranje karstne izdani vrši se preko mnogobrojnih karstnih vrela, formiranim po obodu masiva, na kontaktu sa vodonepropusnim najčešće neogenim tvorevinama. Dreniranje izdani odvija se preko vrela (Moravica, Ozren, Sokobanjsko vrelo, Bele vode, Krkino kućište I i II, Resnik i dr.), ali i preko termomineralnih izvora u Sokobanji (Stojadinović 2018).

PRIMENA METODE

Određivanje ranjivosti podzemnih voda otpočeto je definisanjem faktora O. Formiranje karte ovog faktora izvršeno je sumiranjem zaštitne uloge zemljišta i zaštitne uloge stena u nadizdanskoj

and fracture types of aquifer do not have significant distribution, and therefore they are with insignificant hydrogeological potential.

The karst aquifer formed in limestone and dolomite of Mesozoic age has the largest distribution. In addition to the considerable presence of outcrops, the carbonate complex falls deep below the surrounding tertiary basins (Stojadinović 2018).

The largest part of the karst groundwater originates from the infiltration of precipitations and to a small part of the infiltration of surface streams. The most intensive recharge of the karst aquifer is done in parts on karst massifs with a lack of vegetations, especially where surface karstic features are developed, as it is the case on karst massive Ozren and Devica. The recharge from surface streams is proved at the sinking streams Tisovik and Izgara. (Stevanović 1991).

Drainage of the karst aquifer is carried out through numerous karstic springs, formed along the periphery of the massif, in contact with low permeable, mostly neogene formations. Drainage is issued through the springs (Moravica, Ozren, Sokobanja spring, Bele vode, Krkino kuciste I and II, Resnik, etc.), but also through thermo-mineral springs in Sokobanja (Stojadinović 2018).

APPLICATION OF THE METHOD

Determination of groundwater vulnerability was initiated by defining of factor O. The analysis of this factor was performed by summing the protective role of the soil and the protective role of the rocks in zoni. Za definisanje uloge zemljišta analiziran je granulometrijski sastav i debljina svakog od prisutnih tipova zemljišta, dok je uloga stenske mase određena na osnovu karakteristika litoloških članova i njihove ispucalosti, ali i debljine svakog litološkog člana ponaosob. Procena debljine stena u nadizdanskoj zoni je izvršena tako što je od digitalnog elevacionog modela terena (DEM) oduzeta karta nivoa podzemnih voda. Prisustvo zemljišta male debljine ili čak njegovo odsustvo, ali i relativno mala dubina do nivoa podzemne vode u karstnim terenima uslovili su veoma malu zaštitnu ulogu nadizdanske zone na pojedinim delovima terena.

Zatim se pristupa određivanju faktora C, i tom prilikom su posebno razmatrana dva scenarija, odnosno slivno područje ponora i ostatak područja.

Obzirom da se područje istraživanja ne odlikuje prisustvom klasičnih ponora, već prisustvom vodotokova koji poniru, izvršena je analiza smanjenja zaštitne uloge nadizdanske zone za slivno područje ponirućih tokova. Tom prilikom analizirani su parametri kao što su rastojanje od površinskog toka, nagib terena i vegetacija, da bi se delovi terena bliže ponornicama, sa većim nagibom terena i odsustvom vegetacije okarakterisali kao tereni gde je smanjena zaštitna uloga nadizdanske zone. Sa druge strane, kod ostatka područja, izvršena je kategorizacija terena sa aspekta razvijenosti površinskih karstnih oblika, njihove pokrivenosti, i odnosa nagiba terena i vegetacije. U ovom slučaju najvećim smanjenjem zaštitne uloge karakterišu se delovi terena sa visokim stepenom razvijenosti karstnih oblika koji odgovaraju delovima terena sa prisustvom vrtača, malim nagibom terena i prisustvom vegetacije.

Za određivanje uticaja padavina tj. faktora P posebno su analizirana dva parametra: godišnja suma padavina i intenzitet padavina. Na osnovu dostupnih podataka celo područje istraživanja svrstano je u jednu klasu i po prvom i po drugom parametru, te je sumiranjem vrednosti ova dva parametra dobijena vrednost faktora P koja odgovara veoma malom smanjenju zaštitne uloge nadizdanske zone.

Izrada finalne karte ranjivosti izvršena je preklapanjem karata faktora C, O i P, odnosno njihovim množenjem u svakoj tački istražnog područja, pri čemu je na osnovu dobijenog COP indeksa izdvojeno 5 klasa ranjivosti (***Slika 3***). Veoma visokom ranjivošću (crvena boja) karakterišu se tereni na kojima je izraženo prisustvo površinskih karstnih oblika i tereni u slivu ponornice Tisovik i reke Izgare. Visokom ranjivošću (narandžasta) odlikuju se karstni tereni neposredno oko delova sa veoma velikom ranjivošću, ali i delovi terena izgrađeni od krečnjaka sa odsustvom zemljišnog sloja i vegetacije. Najveći deo terena izgrađenih od karbonatnih stena odlikuje se srednjom ranjivošću (žuta), a samo manji deo malom (svetlozelena). Svetlozelenom i zelenom bojom označeni su tereni sa niskom, odnosno veoma niskom

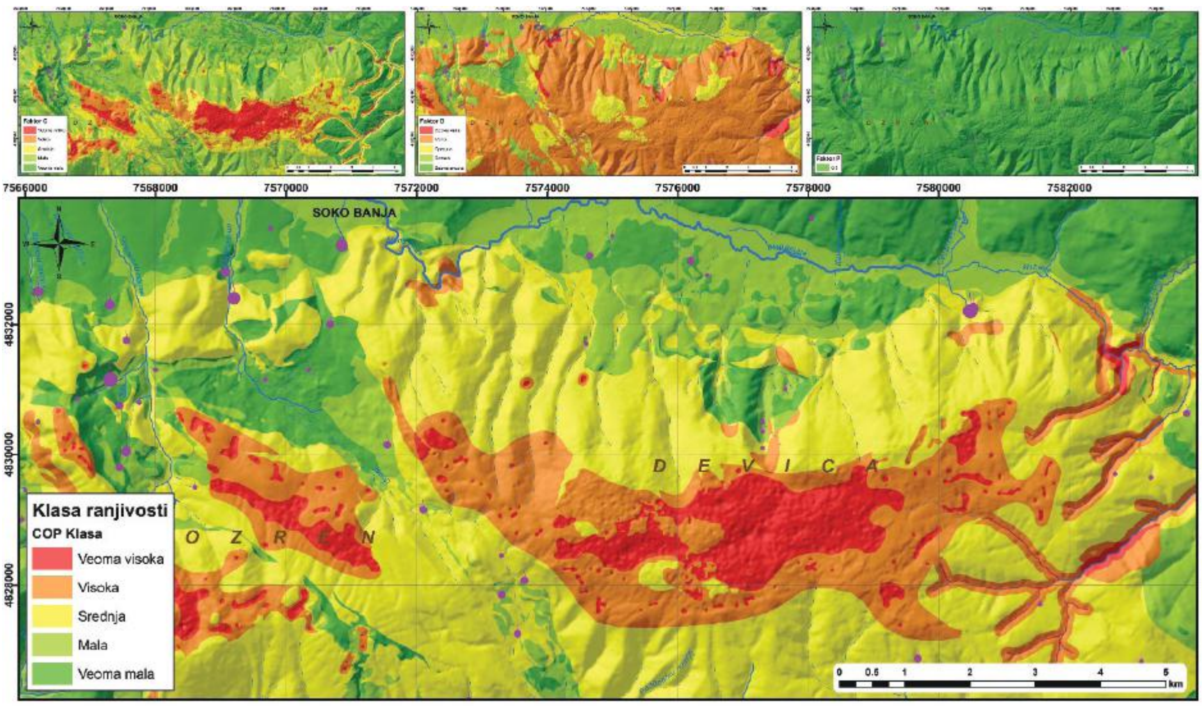
the zone of aeration. In order to define the role of the soil, the granulometric composition and thickness of each of the present soil types were analysed. The role of the rock mass was determined on the basis of the characteristics of the lithological members and degree of cracking, as well as the thickness of each lithological member separately. The estimation of the rocks thickness in the unsaturated zone was done by subtraction of the groundwater level map from the digital elevation model (DEM).

The presence of low-thickness soils or even it's absence, but also a relatively small depth to the groundwater level in the karst terrain, have caused a very low protective role of the unsaturated zone on certain parts of the terrain.

The next step was determination of factor C where two scenarios were considered: the catchment area of the ponor and the rest of the area. Since the research area is not characterized by the presence of classical sinks, but by the presence of sinking streams, an analysis of the reduction of the protective role of unsaturated zone for the catchment area of the sinking streams was done. In this scenario, parameters such as distance from surface flow, terrain slope and vegetation were analysed, so that terrain closer to the sinks, with a greater slope and absence of vegetation were characterized as terrain where the protective role of the unsaturated zone is reduced. On the other hand, in the rest of the area, the categorization of the terrain was made from the aspect of the development of karst surface features, their coverage, and the degree of the terrain slope and vegetation. In this case, the greatest reduction of the protective role is characterized by the terrain parts for a high degree of development of the karstic features corresponding to the parts of the terrain with the presence of the sinkholes, with small terrain slope and the presence of vegetation.

To determine the impact of precipitation, i.e., factor P, two parameters are analysed: the annual amount of precipitation and intensity of precipitation. Based on the available data, the whole research area is classified into one class by the first and second parameter. Summing the value of these two parameters, the value of the factor P was obtained and corresponds to a very small reduction in the protection role of unsaturated zone.

Creation of the final vulnerability map was done by overlapping the maps of factors C, O and P, and by multiplying them at each point of the research area. As a result, five vulnerability classes were single out based on the obtained COP index (***Figure 3***). Terrains where the surface karst features are present and by catchment area of Tisovik and Izgara sinking river are characterized by very high vulnerability (red colour). High vulnerability (orange) is present for karst terrains directly around the parts with very high vulnerability, but also for parts of the terrain formed of limestone with the absence of soil layer and vegetation. The largest part of the



Slika 3. *Karte faktora C, O i P (sa leva na desno, gore) i karta COP indeksa (dole) (Stojadinović 2018)*
Figure 3. *Maps of factor C, O and P (from left to right, top) and map of COP index (below) (Stojadinović 2018)*

klasom ranjivosti i njima pripadaju tereni izgrađeni od nekarbonatnih stena. Izuzetak predstavljaju tereni izgrađeni od krečnjaka paleogene i neogene starosti, a koji su na karti obojeni svetlozelenom bojom.

ZAKLJUČAK

Dobijena karta ranjivosti podzemnih voda može se koristiti kao dobra podloga u planiranju i menadžmentu podzemnih vodnih resursa, a primarno kao smernica u razvoju strategije zaštite podzemnih voda. Ova podloga je posebno bitna ako se uzme u obzir intenzivan turistički razvoj Sokobanje.

Na karti su izdvojene značajne površine koje se odlikuju velikom do veoma velikom ranjivošću podzemnih voda. Ovi delovi terena podložni su lakom zagađenju u slučaju ispuštanja zagađujuće supstance na površini terena. Relativno dobar kvalitet podzemnih voda okoline Sokobanje jeste rezultat relativno male naseljenosti i odsustva potencijalnih izvora zagađivanja u sadašnjim uslovima. Međutim, razvoj turizma i urbanizacija ovog područja, u budućnosti mogu da ugroze kvalitet podzemnih voda. Da bi se obezbedio dobar kvalitet podzemnih voda na dugoročnom nivou, neophodno je, da se prilikom njihove zaštite uzmu u obzir i rezultati dobijeni izradom karata ranjivosti podzemnih voda.

Dobijena karta ranjivosti mogla bi se koristiti i pri izradi karte koja pokazuje koliki je rizik od zagađivanja podzemnih voda, dok se direktna primena dobijene

terrain formed of carbonate rocks is characterized by medium groundwater vulnerability (yellow), and only a small part with the low vulnerability (light green). Light green and green are marked terrains with a low, i.e., very low vulnerability degree and are present in terrains formed of non-carbonate rocks. The exception are the terrains formed of limestone from Paleogene and Neogene age, represented with a light green colour on the map.

CONCLUSION

The obtained groundwater vulnerability map can be used as a good base for planning and management of groundwater resources, and primarily as a guideline in the development of groundwater protection strategy. This basis is especially important if we take into account the intensive tourism development of Sokobanja Spa.

Significant areas are distinguished on the map, which are characterized by high to very high groundwater vulnerability. These parts of the terrain are susceptible to easy contamination in case of contaminant release at the surface of the terrain. The relatively good quality of groundwater of the Sokobanja region is due to the relatively low population density and absence of significant potential sources of contamination. However, the development of tourism and urbanization of this area may in the future endanger the quality of groundwater. In order to ensure good groundwater quality on a long-term basis, it is necessary to take into account the results of groundwater vulnerability assessment during their protection.

The obtained vulnerability map could also be used in the development of a map showing the risk of groundwater contamination, while the direct application of the groundwater vulnerability map refers karte ranjivosti podzemnih voda odnosi na određivanje zona sanitarne zaštite izvorišta vodosnabdevanja.

to the determination of the sanitary protection zones of existing water supply sources.

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