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МАКЕДОНСКО ГЕОЛОШКО ДРУШТВО

ВТОР КОНГРЕС
на
Геолозите на Република Македонија

ЗБОРНИК НА ТРУДОВИ

Уредници:
Јовановски, М. & Боев, Б

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ПРЕДГОВОР

Геолошката наука на територијата на Република Македонија има долга традиција, а е поврзана пред се со рударската активност. Познати се локалитети каде се најдени монети од бакарната и бронзената доба. Сочувани се траги на експлоатација на злато од речниот нанос на Коњска Река-Гевгелиско и на други места, од времето на Александар Македонски. Во источна Македонија рударењето било интензивно за римско време.

Први геолошки податоци на научна основа за територијата на Македонија се јавуваат во првата половина на XIX век, а првите печатени геолошки трудови за нашите простори се среќаваат кај А.Буе (1828-1870) и Виксенел (1842). Од крајот на XIX век па се до денес во зависност од интензитетот на истражувањата напишани се голем број на трудови од сите области на геологијата.

Активностите на стручните лица од областа на геологијата се изведуваат преку Македонското Геолошко Друштво кое е формирано во 1952 година.

Во 2008 година се одржа Првиот Конгрес на Геолозите на Република Македонија од кој излезе зборник со преку 50 научни трудови од кои добар дел беа подготвени од меѓународни тимови.

Во периодот помеѓу 2008 и 2012 година во нашата земја се изведоа голем број на активности во сите полиња на геологијата. Особено важни да се споменат се интензивните истражувања на метални и неметални минерални суровини, регионалните, геохемиските и инженерско-геолошките, итн.

Вториот Конгрес на Геолозите на Република Македонија претставува сублимат на научните сознанија базирани на споменатите геолошки истражувања и испитувања кои се одвиваа на територијата на нашата земја во периодот од 2008-2012 година. Исто така, на конгресот е презентирана и дел од работата на колеги геолози од соседните земји, така да и овој пат со задоволство може да констатираме дека конгресот има меѓународен карактер.

PREFACE

Geological science on the territory of Republic of Macedonia has long tradition, and is mainly connected to the mining activities. There are numerous localities where coins from copper and bronze age are found. Traces from exploitation of gold in the river Konjska-Gevgelija and other places are known, in the time of Alexander the Great. In eastern Macedonia the mining was very intensive during the Roman period.

First scientific geological data for the territory of Macedonia are found in the first half of XIX century, and the first printed papers for our region are found at A.Bue (1828-1870) and Viksenel (1842). From the end of XIX century until today, depending on the intensity of the investigations numerous publications are presented in all fields of geology.

The activities of geological scientists are performed in the frame of the Macedonian Geological Society which is formed in 1952.

In 2008 the First Congress of Geologists of Macedonia was held. Proceedings with over 50 papers were published. Numerous papers were prepared by international teams.

In the period between 2008 and 2012 investigations in all fields of geology were performed. Especially important to mention are the investigations of metallic and non-metallic mineral resources, regional, geochemical, engineering-geological, etc.

The Second Congress of Geologists of Republic Macedonia presents sublimate of scientific knowledge based on the mentioned geological investigations which were conducted in the period 2008-2012. Also, the congress presents part of the work of colleagues from neighboring countries, so with great pleasure we can once again confirm its international character.

Претседател
на организационен одбор

President
of organizing committee

Проф. д-р Милорад Јовановски

СОДРЖИНА

CONTENTS

COMPARATIVE ANALYSIS OF APPLICATION OF DRASTIC AND PI METHOD IN THE PROTECTION OF NATIONAL PARK TARA GROUNDWATERS

Vladimir Živanović[1], Veselin Dragišić[2], Igor Jemcov[3], Nebojša Atanacković[4]

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Abstract

Methods for groundwater vulnerability assessment are becoming more and more important especially when it comes to groundwater protection. Maps that are obtained by applying these methods are of particular importance because they represent an important basis used to establish groundwater protection preventive measures. These maps can also find wide application in the protection of certain areas as is the case with the National Parks.

The paper describes the use of DRASTIC and PI methods to assess the vulnerability of the National Park Tara groundwaters. Selection of the proper methods for assessing the vulnerability is not an easy task, because each method requires a different level of input data and gives different results, especially if the terrain is characterized by a complex hydrogeological composition. This problem is expressed in karst terrains, where some methods do not take into account the specific characteristics of the karst aquifers. Such is the case with the DRASTIC and PI method application, and therefore this paper comparatively showsthe results that are obtained by applying these methods.

Key words:groundwater vulnerability, karst aquifer, DRASTIC method, PI method, National Park Tara

INTRODUCTION

The concept of groundwater vulnerability assessment was presented in the 60s of the 20th century by a French scientist Margat (Vrba and Zaporozec [1]). The idea was to describe the degree of groundwater vulnerability to pollution as a function of geological, hydrological and hydrogeological conditions of the environment. Ever since then various methods have been developed some of which have become a standard tool for groundwater vulnerability assessment (Gogu and Dassargues [2]). That is the case with DRASTIC method, Alleret al. [3], which has been applied in many countries and in different hydrogeological environment so far (Hamza et al. [4], Denny et al. [5], etc). However, although it has often been applied, this method has various disadvantages, especially when karst groundwater vulnerability is assessed. Exactly for this reason during the last decade certain methods appeared and they were designed in such a way to take into account specific recharge conditions of the karst aquifer (EPIK method - Doerfliger and Zwahlen [6], COP method – Vias et al. [7], etc.). One of these methods is the PI method (Goldscheider [8]) which not only that takes into account specific infiltration conditions in karst terrains, but also gives a good estimation of the protective role of the unsaturated zone in the areas with other type of aquifers as well.

This paper shows methodology of application of DRASTIC and PI methods aiming to show the differences in vulnerability maps produced by application of these methods. We have various examples of application of different methods on the same area in practice (Vias et al. [9], Ravbar and Goldscheider [10]). The results produced were very often different, and sometimes even contradictory.

National park Tara (NP Tara) was chosen to be the test area for application of these methods. The geological structure of this region is dominated by carbonate formations which are highly karstified and represent significant reservoirs of karst groundwater. That is why one of the objectives of this paper was to show how important it was to apply methods which werespecifically designed to assess the vulnerability of karst groundwater in order to evaluate properly the protective role of unsaturated zone, and thus prepare a good basis for protection of this natural resource.

EXPERIMENTAL SECTION

One of the first and most used methods for groundwater vulnerability assessment is DRASTIC method (Aller et al. [3]). Analysing the characteristics of the aquifer and vadose zone, groundwater level, topography and infiltration conditions, this method considers the behaviour of pollutants from the surface which are infiltrated with rain. The method uses seven parameters: depth to groundwater level (factor D), recharge (P factor), the aquifer media (factor A), soil type (factor S), topography of the terrain (factor T), the influence of the aeration zone (factor I) and transmissibilityof the aquifer (factor C). In the process of entire vulnerability calculation, to each factor the weight coefficient is added. This coefficient defines the importance of the factor in defining the natural protection. Thus the size of the vulnerability, or so called DRASTIC index,is calculated by the formula:

$$DRASTICIndex = 5 \cdot Dr + 4 \cdot Rr + 3 \cdot Ar + 2 \cdot Sr + Tr \cdot Tw + 5 \cdot Ir + 3 \cdot Cr.$$

The numbers in front of each of the factors are values pointing the importance of individual factors on the vulnerability index. Vulnerability map is obtained when the terrain is classified into 6 different classes, from very high to very low groundwater vulnerability.

PI method was developed under the project COST 620 (Zwahlen[11]) at the Department of Applied Geology (University of Karslruhe). PI method is GIS-based approach for mapping groundwater vulnerability of all types of aquifers, with special focus to the karst aquifer. Acronym PI points out that 2 parameters are considered: a protective factor P and the infiltration conditions I.

P factor describes the protective function of the layers that lie between the terrain surface and groundwater levels –soil, non karstified rocks and unsaturated karstified rocks. P factor is calculated by the updated version of the German GLA method (Hölting et al. [12]). By this factor, the land is classified into 5 classes where P=1 corresponds to the class with the lowest level of protection and P=5 corresponds to the highest level of protection.

The I factor describes the infiltration conditions, i.e. degree to which the protective cover is being bypassed as a result of the lateral surface and subsurface flow in catchment of the ponors or sinking streams. In defining this factor, the catchment of the ponors or sinking streams is first being determined. Then, based on the character of the slope, vegetation and soil, the movement of pollutant from the surface to the zones of concentrated infiltration is being estimated. Values range from 0-1 where the lowest values indicate rapid infiltration conditions with bypassing the protective role of the unsaturated zone.

The final factor π is calculated as the product of P and I values:

$$\pi = P \cdot I$$

According to π factor, the land is divided into five classes. Values $\pi \leq 1$ indicates a small degree of protection and extreme vulnerability to contamination. In contrast, the value of $\pi = 5$ indicates a high degree of protection and very low vulnerability. Spatial distribution of factors of π is shown on the vulnerability map.

For the application of these two methods and for the creation of the vulnerability maps as a test area the territory of Tara National Park is chosen. The National Park covers an area of 192 km^2 and covers most of Tara Mountain. It is located in the far west of Serbia on the border with Bosnia and Herzegovina.

Carbonate rocks of Mesozoic age dominate in the structure of mountain Tara (Fig. 1). Palaeozoic schists, Jurassic diabase and gabbro, and Quaternary sediments are with limited distribution. From the hydrogeological point of view, karst aquifers have the largest distribution within the research area. This type of aquifer is the most important in the area because of the largest groundwater accumulation and because almost the entire quantity of water of mountain Tara drains through it.

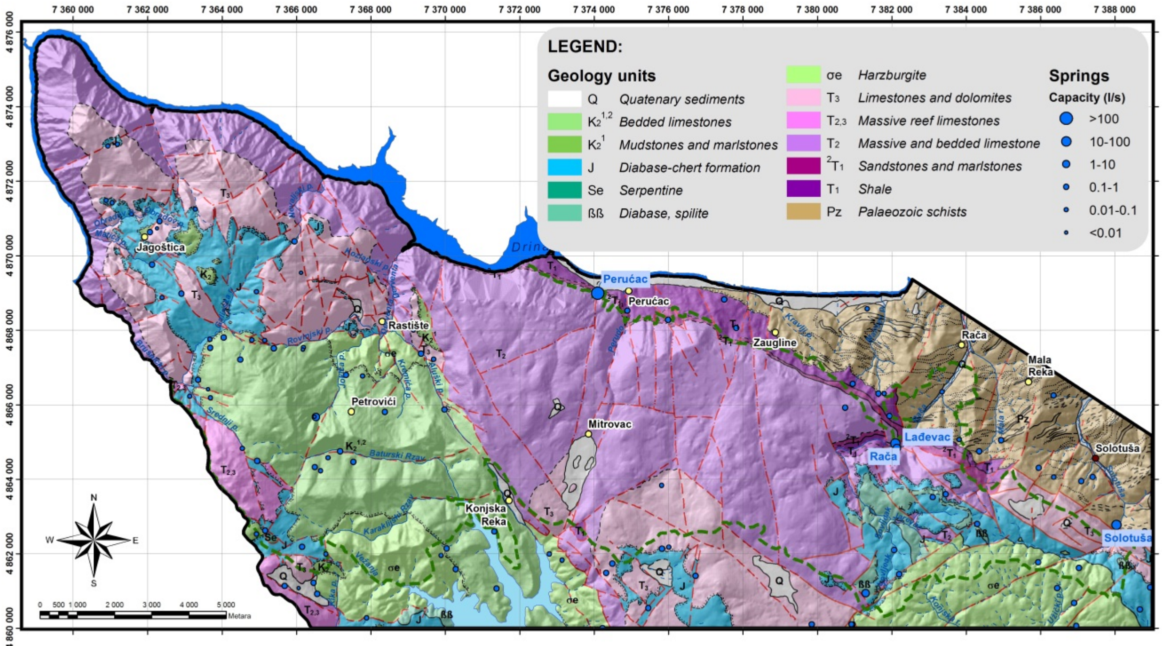

Figure 1. Geological map of the National Park Tara (Olujuć and Karović[13])

Q –Quaternarysediments (intergranular aquifer); $K_2^{1,2}$ – bedded limestones (karst aquifer); K_2^1 – Mudstones and marlstones (fissured aquifer); J – Diabase-chert formation (fissured aquifer); Se, ββ,σe – Serpentinite, diabase, spilite, harcburgite (fissured aquifer), T_3, $T_{2,3}$, T_2 – limestones and dolomites (karst aquifer); $^2T_1$ – sandstones and marlstones - (fissured aquifer); T_1 – shale (low permeable rocks); Pz – Palaeozoic schists(low permeable rocks)

Karst aquifer recharge is highly dependent on the meteorological conditions and the composition of soil and vegetation cover. Sum of annual precipitation in this area is around 1000 mm. Infiltration of precipitation is done on the entire karst plane, but the intensity is greatest in places of concentric infiltration - sinkholes, karst valleys (Ljuto and Dobro polje), pits and ponors (Jaruga ponor, ponor near the spring Zaboj, Vasić ponor, ponor in Mitrovac, Lokvica ponor, ponor in KrnjaJela et al., Jemcov [14]).

Aquifers drainage is mostly done through a karst springs with different yield. The locations of the springs are related to the main fault zones or crossing of some faults, and thus the largest karst springs within the research area (Perućac, Lađevac and Rača) are related to the tectonic zones. The largest spring in the investigation area is the Perućac spring with a minimum yield of 450 l/s (Jemcov [14]).

RESULTS AND DISCUSSION

The application of DRASTIC method

Making a map of groundwater vulnerability of NP Tara by applying DRASTIC method require the creation of 7 different layers, i.e. 7 maps for each analysed parameter. On these maps different areas are isolated according to the influence of the analysed factor on the groundwater vulnerability.

Map of factor D (depth to groundwater level) was obtained by the spatial analysis of the factors which have impact on the size of the vadose zone, Živanović [15]:hydrogeologi-cal characteristics of the rocks on one side and the nearness of water occurrences such as springs, rivers and lakes on the other. Based on the location of water occurrences, first a map that shows how much each point on the ground is away from any spring or river is done (buffer zones of 20, 50, 100 and 500 m). This map is combined with the hydrogeological map of the National park and as a final resulta map that shows the influence of the depth to groundwater on the vulnerability is done.

For mapping of recharge (R factor), following layers were used through a special calculation scheme (Piscopo [16]): 1.layershowing the terrain slope that was made on the basis of DEM using slope analysis; 2.layer showing spatial distribution of rainfall (average yearly precipitation values from existing rainfall stations were used); 3 layer showing soil composition was done based on existing pedological maps (terrain classification was made according to the soil permeability). Joining these layers a new map is created where the recharge is estimated according to the sum of points assigned to each particular layer.

The parameters A, C and I are relatively easily determined based on the known geological and hydrogeological situation in the research area. Factors A and I are determined descriptively, based on the ranging values given from the authors of the DRASTIC method. Depending on the nature of the rocks in the saturated and unsaturated zone values in the range of 2 to 10 are assigned. The factor C depends on the filtration coefficient of the rocks which formed the aquifer. Filtration coefficient was estimated based on the lithological composition and the degree of cracking and karstification of these rocks.

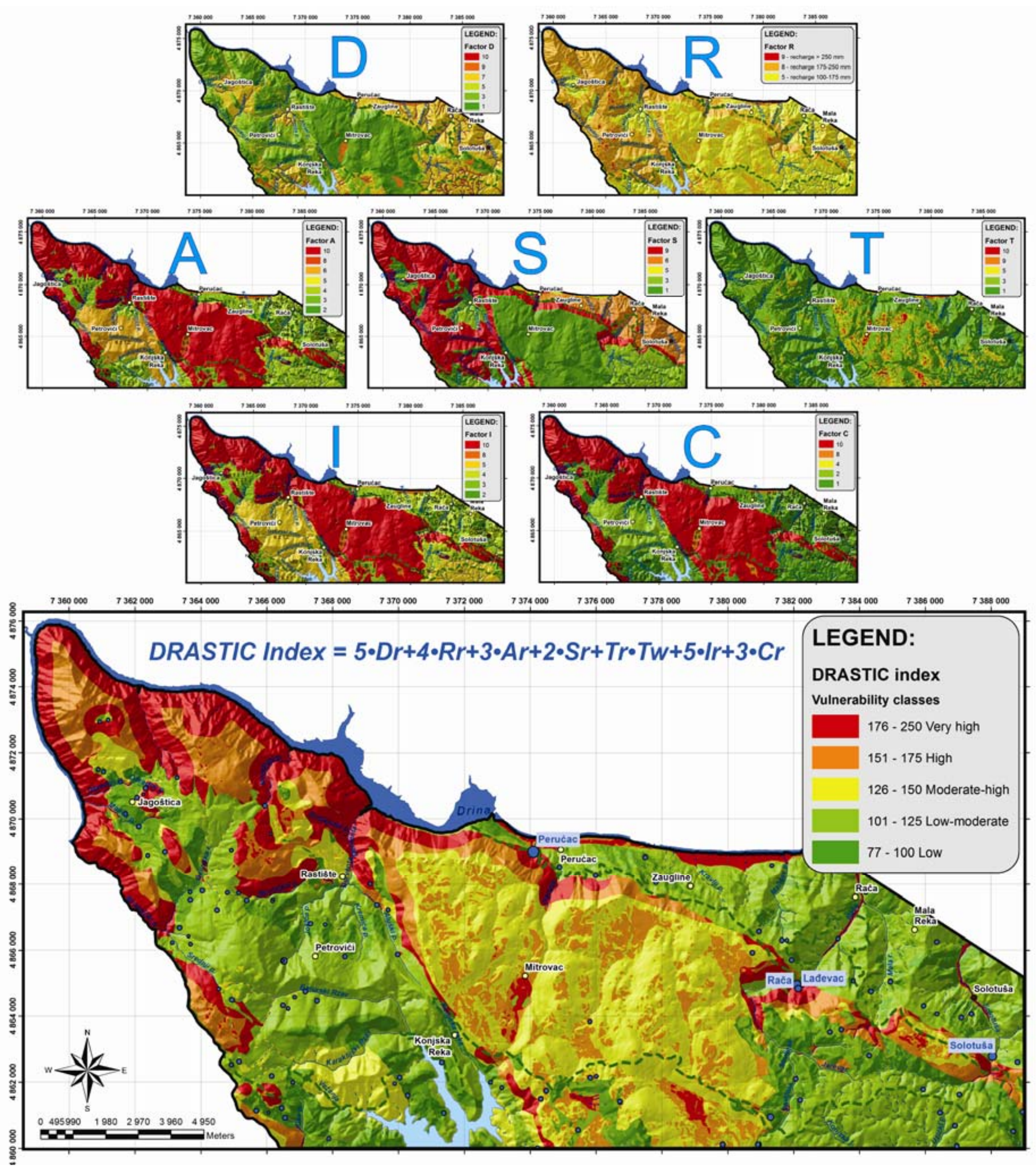

Figure 2. Creation of the groundwater vulnerability map of the National Park Tara using the DRASTIC method

Pedological maps at a scale 1:50000 were used for creation of factor S map. Each soil type on the map is characterized by specific grain size composition on the basis of which the ranking of this factor is made. For the creation of factor T map, classification of the slope map maid with spatial analysis of the DEM was done. The DEM is made in the scale of 1: 25 000 in total surface of 265 km^2.

Using the DRASTIC equation, final vulnerability index is calculated and based on it, different zones (classes) with different degree of groundwater vulnerability to contamination from the surface were separated (Fig. 2).Five of the six classes of groundwater vulnerability have been allocated pointing out low to very high vulnerability.

The application of PI method

The first step in applying the PI method is to determine the protection factor P which describes the protective function of the layers that lie between the terrain surface and groundwater levels - topsoil, subsoil, non-karstified rocks and karstified rocks in the unsaturated zone.

For this purpose, first the map of effective field capacity (EFC factor) was made. This parameter was calculated based onthe pedological maps of the research area, where for each pedological unit estimationof the thickness and grain-size was done (Jemcov [14]). After making the EFC map, assessment of the protective function provided by the soil and the rocks in the unsaturated zone was done.

To determine the protective role of rock masses in the unsaturated zone, scoring was performed according to the type of rock (parameter L) where each L value was multiplied by the parameter F, which determines the degree of cracking or the degree of rock karstification. This product was then multiplied by the thickness of rock in the unsaturated zone.

To determine the P factor, it was also necessary to determine the size of the groundwater recharge because based on it the correction factor R,which reduces or increases the protective function of the soil and thevadosezone,was calculated. For recharge estimation, the same methodology as in the DRASTIC method was used. Combining all these parameters final P factor map was obtained.

In determining the I factor it was first necessary to determine the dominant flow of surface water movement. This was done based on the estimatedfiltration coefficient of the upper part of the soil. To define the direct infiltration conditions it was also necessary to determine the slope and the vegetation of the terrain. The vegetation map was developed based on the satellite image where the terrain was classified into two categories: 1. meadows, pastures and fields and 2. forests. According to the degree of slope, zoning was done into 3 groups. Combining these three parameters I' map was obtained.

For creation of the final I map, it was also necessary to create the map of catchment areas. Ponor zones and zones with different distance from the ponors and sinking streams (buffer zones) are isolated on this map. Areas which gravitate towards the karst terrain as well as the areas which represent draining zonesoutside of karst are also isolated on this map. By combining the I 'map and the catchment area map wecreated the I factor map which shows the degree to which the protective role of the unsaturated zoneis bypassed.

Groundwater vulnerability map was created by determining the π factor which was done by multiplying P and I factors in each point of the research area. The resulting map shows general vulnerability and natural protection of groundwater from the highest aquifer. The value of π factor is in the range between 0.0 and 5.0 with high values indicating a high degree of natural protection and low vulnerability (Fig. 3).

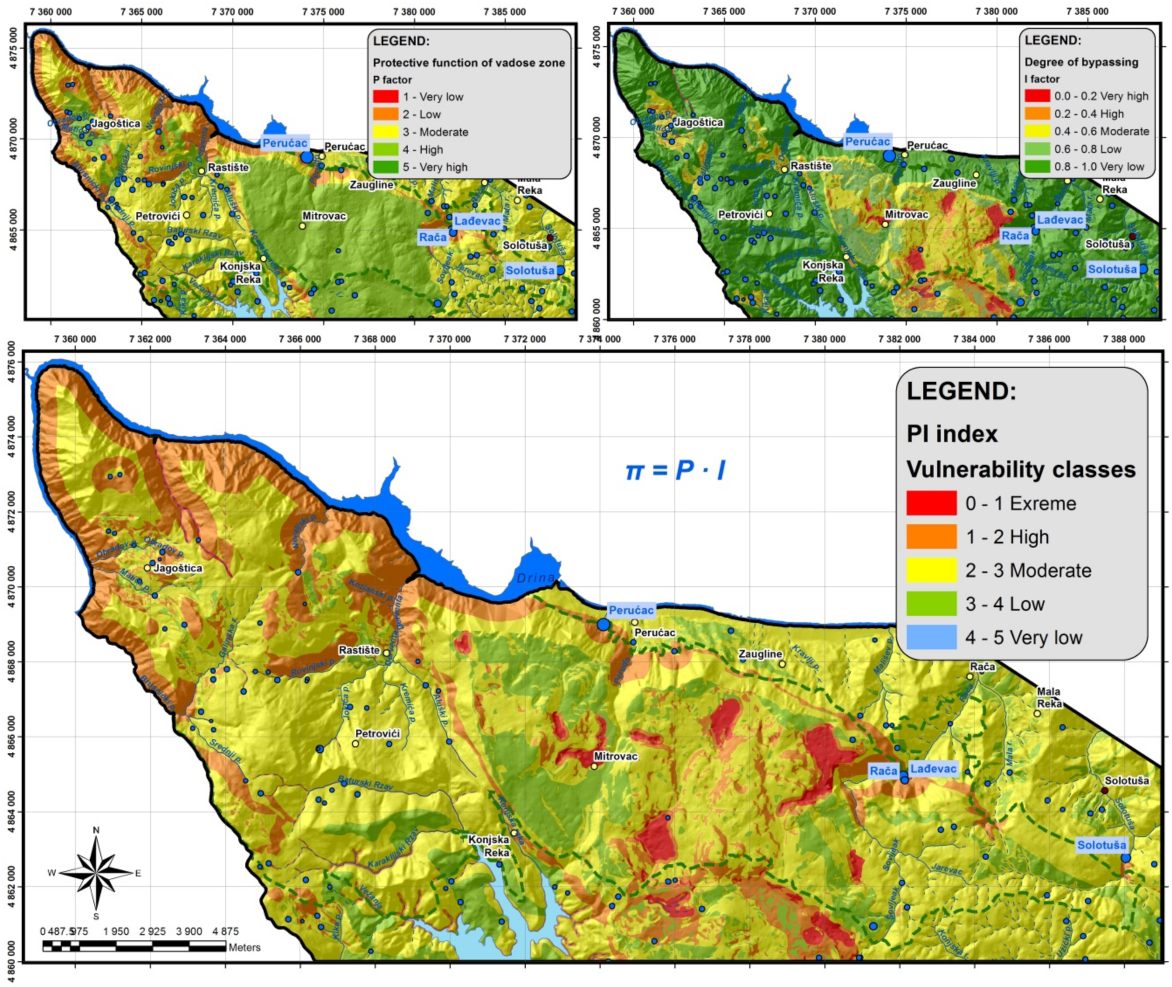

Figure 3. The final PI vulnerability map which was made by intersecting the P and the I map

By applying the DRASTIC method a vulnerability map was produced containing different vulnerability classes with equal percentage of participation. Very high vulnerability class covers around 15% of the research area and is mainly distributed in the northwest part of the National park. Moderate and high vulnerability are mainly isolated on the karst plateau around Mitrovac. Low groundwater vulnerability characterizes the biggest part of the research area (44.5%) and it is the most widespread in the areas with developed fissured type of aquifer as well as the terrains made of low permeable rocks.

By applying the PI method a map with the largest part of the terrain (63,4%) belonging to the moderate groundwater vulnerability class was produced. The northwest part of the park is characterized by high vulnerability. Very high vulnerability class which covers only 2.2% is isolated in the zone of ponors and dolines on the karst plateau around Mitrovac. Low vulnerability is also isolated on the karst plateau around Mitrovac, in parts outside the catchment area of ponors, where the groundwater level is deep and where there is clayey soil in surface parts.

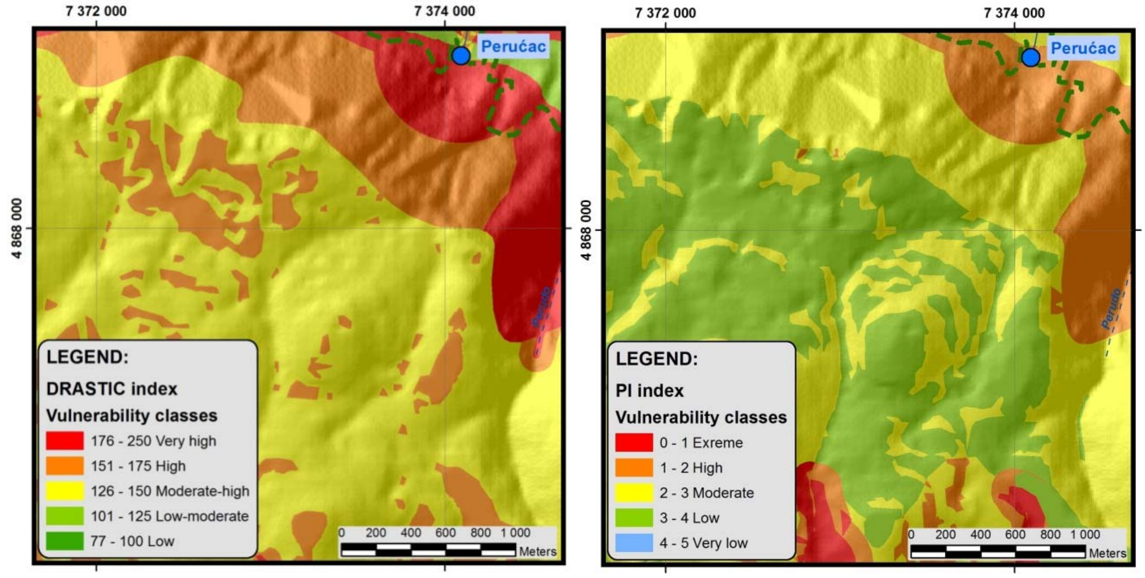

Figure 4. Difference between vulnerability maps obtained using DRASTIC and PI method for the karst plateau above Perućac karst spring

CONCLUSION

On the basis of analysis done by applying DRASTIC and PI methods, it can be concluded that the degree of groundwater vulnerability is directly influenced by karst distribution. Zones with very high and high groundwater vulnerability are isolated in these terrains by applying DRASTIC method. However, PI method recognizes low groundwater vulnerability in some parts of karst (the part of the karst plateau above Perućac karst spring) since it pays much more attention to the depth to groundwater level and pedological characteristics of the ground (Fig. 4).

The differences in vulnerability maps produced in this way are the result of the fact that PI method is created to take into account specific characteristics of karst terrains. By applying PI method conditions of surface water infiltration are analysed, bearing in mind the existence of ponors and ponor zones as well as the zones gravitating towards them. That explains low vulnerability of some karst terrains outside the catchment areas of ponors. These terrains are characterised with deep groundwater level and thick clayey soil which significantly reduced the infiltration of pollutants from the surface.

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