GROUNDWATER VULNERABILITY DETERMINATION OF NORTHEASTERN BOSNIA ACCORDING TO DRASTIC METHOD

Srkalović Dado[1], Željka Stjepić Srkalović[2]
[1]Faculty of mining, geology amd civil engineering Tuzla, e-mail: dadosrkalovic@gmail.com
[2]Faculty of Sciences and Mathematics Tuzla, e-mail: zeljka.stjepic-srkalovic@untz.ba

The paper assesses the vulnerability of groundwater bodies in the basin of the river Bosna and Spreča, then the river basin of the Drina river (Drinjača), as well as parts of the immediate Sava river basin (Čelić area - Gnjica river and Turija basin) by the DRASTIC method. All water bodies were analyzed in terms of groundwater depth, roof sediment thickness, infiltration, slope angle, hydraulic conductivity and lithological composition of aquifers. The pollution potential formula was used to assess the vulnerability of groundwater.

Key words: groundwater bodies, groundwater, DRASTIC method, northeast Bosnia

INTRODUCTION

The term "groundwater vulnerability to pollution" was first used by MARGAT in 1968. The term 'groundwater vulnerability' is used in opposition to the term 'natural pollution protection'. Although many efforts have been made to come up with a common groundwater vulnerability concept, different authors still use it under different conditions. In 1988, FOSTER & Hirata defined "aquatic pollution and vulnerability" as the sensitivity of different parts of an aquifer to negative loads (FOSTER & HIRATA, 1988).

PHYSICAL-GEOGRAPHICAL POSITION OF NORTHEASTERN BOSNIA AND HERZEGOVINA

Geographical position. The exploration area is contoured by the rivers Sava in the north, Drina in the east, Bosnia in the west and the rivers Drinjača and Krivaja in the south. The area covers about 6350km2 and belongs to the most populated part of Bosnia and Hercegovina (Figure 1).

Northeast Bosnia is located within geographical coordinates from 43˚55'19 " to 45˚05'40 " N and from 18˚11'14 " to 19˚37'41 " E.

Geological characteristics. Territories belonging to the study area of northeastern Bosnia are in the Central and Inner Dinarides. Beginning in the south, the Paleozoic shales and Mesozoic limestones were separated in the Central Dinarides, followed by the Jurassic-Cretaceous and Upper Cretaceous flysch zones (Fig. 3). Northern of these flyschs the Inner Dinarides are extending, which can be divided into two zones (Hrvatović, 2006). The first is the central ophiolite zone, which is crossed by the Bosna River on a profile that starts about 5 kilometers northern of Vranduk and ends in the Doboj region. The second zone is located northern of Doboj towards the Sava River, in the area where the riverbeds of Bosnia intersect the formations of the Horst and Trench Zone (Čičić, 2002).

The ophiolite zone is represented by ultramafic rocks (peridotite, dunite, and serpentinite, which is the product of hydrothermal alterations of peridotite and dunite) and subordinate to gabbro, diabase, basalt, and spilites. It is divided into Upper Jurassic ophiolite melange, ophiolite complex and rocks deposited over the massif. The melange consists of a slate-silt matrix with fragments of grauvaca, ultramafites, gabbro, diabase, basalt, tuff, amphibolite, hornfels and limestone blocks of various ages and conditions of creation. The youngest limestone fragments are of titonic age (J_3^3). In the area of the Bosna River, northern of Žepče, most of the melange is composed of massive gravels, while in other areas it is dominated by limestones.

Fig.1. The geographic location of the research area (complemented by Srkalović, D. 2015)

Ultramafic rocks occur in the form of centimeter to decimeter fragments or in the form of kilometer-long bodies and of course as large massifs (100-500km^2), such as the Krivaja-Konjuh massif, which is divided into several blocks. The thickness of the ultramafic rocks varies from several hundred meters to 2 kilometers. Some smaller ultramafic massifs, such as Ozren, show often more complex structures than the larger ones (Babajić, 2009; Pamić, 1996; Pamić, 1964; Pamić & Olujić, J, 1974).

The entire area of Semberia is located in the alluvial plane of the Drina River, with an elevation of 85-90m above sea level, with a fairly simple geological composition. It is composed of sedimentary rocks of Quaternary age and tertiary and Mesozoic sediments which occur up to a depth of about 2.5 km (Đurić & Radovanović, 2012).

Geomorphological characteristics. The macro-regional area of northeastern Bosnia is dominated by the block structure of horsts and trenches formed by plioquaternary radial tectonics. The outflow of the Sava and the lower reaches of the Drina, Bosnia, Spreča, Tinja and Tolisa rivers is neotectonically directed by the right horizontal displacements of the of the Sava graben fault, the Spreča fault and the Drina fault.

The largest river meanders are formed by lateral erosion of the Sava River, the biggest river flow in Bosnia and Hercegovina, whose mean annual flows downstream of the mouth of Bosnia exceed 1000m^3 / sec (Žigić, I., Pašić-Škripić, and Srkalović, 2011).

The gradual elevation of the terrain to the south is morphologically expressed by low foothills, which directly neotectonically bind to older fault-block mountain morphostructures with foothill stairs: Konjuh 1328 m asl, Ozren 918 m asl, Majevica 915 m asl and Trebovac 692 m .nm. (Lepirica, 2015).

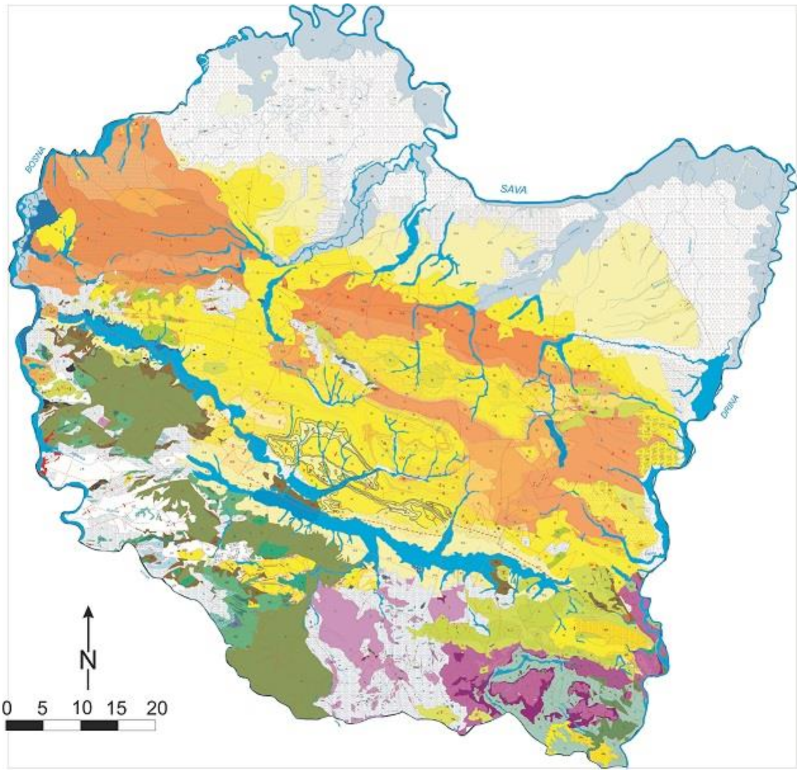

Fig. 2. Geological map of southeastern Bosnia (scale 1:25000) (Čičić, 2002., edited: Srkalović, 2015.)

Spatially smaller valleys of Tuzla, Kotorsko, Doboj, Stanari, Ugljevik and other are orographically contouring the surrounding mountain elevations and low hills. The low positions of valleys and basins of the macro-region are clearly expressed by meandering river beds, floodplains and river terraces (Figure 3).

Climatic characteristics. Northeastern Bosnia is in a temperate continental climate with two distinct seasons (summer and winter) and two transitional periods (spring and autumn).

The main characteristic of this climate is mild winters and moderately warm and humid summers. The whole area is under the influence of the southern branches of the northern temperate zone and the northern parts of the subtropical belt, which are modified by altitude. The southern morphological structure in the Spreča-Majevica region with Semberia changes the thermal and isochthonous regime in the valley-basin region. This region belongs to the Atlantean influences, which in the east of Bosnia and Herzegovina, are modifying the values of the pluviometric regime and reduces it, especially in Semberia, to semi-steppe characteristics.

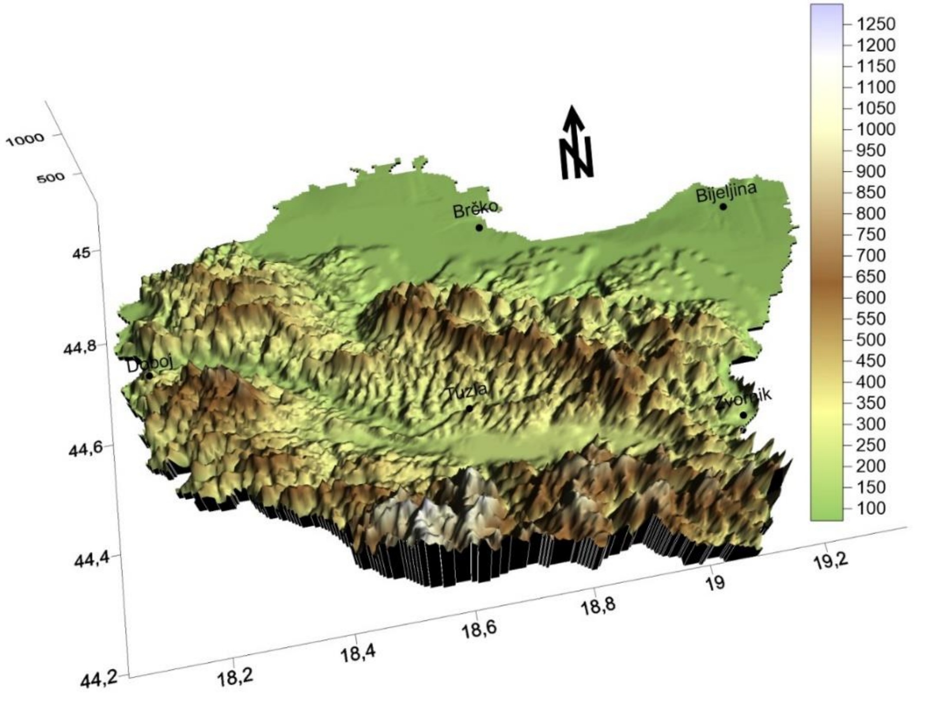

Fig. 3. The relief of northeastern Bosnia (Srkalović, D. 2015)

The average annual air temperature over Northeast Bosnia is 10.1 °C and the average annual rainfall is 928 l/m^2. The coldest month is January (average -0.8 °C) and the warmest month is July (average 19.4 °C), which indicates a relatively high annual amplitude (about 20.2 °C), ie pronounced continental region. It is important to point out that precipitation is decreasing from south to north. The highest quantities were recorded in Kladanj 1.106 l/m^2 and Vlasenica 1.120 l/m^2 (Konjuh and Javor) and the lowest in Bijeljina (Semberija) 735 l/m^2 (Kudumović Dostović, Ahmetbegović, Stjepić Srkalović, 2019).

Hydrogeological characteristics Extensive groundwater reservoirs exist in separate deposits of the Triassic karstified limestones of Zvijezda, Javor, Romanija, Ozren, Konjuh and the Gostelja basin south of Sprečko polje. Near Doboj, hydrogeological fracture-karst porosity collectors were discovered on the left and right sides of the Bosnia River (Čičić, 2002). Separate groundwater reservoirs were formed in the middle and upper Triassic limestones in the Spreča basin in the source part of the left tributary of the Gostelja River. Serpentinites and peridotites act as surface insulators (watertight rocks crossed by cracks).

The Middle Triassic limestones were developed in separate zones near Brateljevići, Turalići and Draguša (Žigić, Pašić-Škripić, Srkalović, et al., 2008). In the lower parts of the terrain, occasional or permanent spills (Brateljevići, Kladanj, Bjelašnica) on the contact with watertight deposits and these limestones are poured

Three types of watersheds have been developed in the Drina River Basin: surface (orographic), subsurface (hydrogeological) and zonal (hydrogeological) (Žigić, Pašić-Škripić, & Srkalović, 2009).

The surface one passes through parts of the terrain where the lithological composition and position of the rocks do not allow the water to penetrate deeper into the lithosphere. These terrains are built of waterproof formations of Werfen, Paleozoic, volcanic-sedimentary formation and ultramafites. The underground hydrogeological watershed is located on a area where the surface and underground watersheds do not coincide or are deep below the of the terrain surface.

Groundwater is drained through springs in Brateljevići, Podpauč, Plahovići, Stanići, Plazača and Lovnica area. In the wider Kladanj area, the most significant sources are Podpauč, Pećina and Plahovići. The most groundwater is poured from the Veliki Bratnik (Qmin = 20 l/s).

From the Javornik Mountain the waters of Kulješim (Qmin = 25 l/s), Bjelašnica (Qmin = 40 l/s) and Lovnica (Qmin = 10 l/s) are draining into the Drinjača river.
The groundwater balance reserves of the Drina River basin on the territory of Bosnia and Hercegovina, considering the size of the basin in the fissure-karst rock masses, were calculated at 4414 l/s. The balance C1 reserves, are about 80%, while A and B reserves are valued by about 20% (Srkalović, 2011).

Table 1: Average annual air temperature (°C), the rainfall amount (l/m2), air humidity (%), cloudiness (1/10) and snow depth (cm) in northeastern Bosnia

Meteo. station	Air temp. (°C)	Rainfall (l/m^2),	Humidity (%)	Cloudiness (1/10)	Snow depth (cm)
Tuzla	10,0	894	78	5,9	97
Kladanj	9,2	1106	77	5,4	129
Gračanica	10,0	829	82	6,8	66
Zvornik	10,7	920	78	5,6	-
Bijeljina	10,9	735	80	5,5	68
Vlasenica	9,5	1120	79	5,3	120
Bratunac	10,4	848	81	6,6	55
Srebrenica	9,7	980	85	5,3	55
Sjeveroistočna Bosna	10,1	928	80	5,8	84

Source: Federal Hydrometeorological Institute Sarajevo, 2010.

RESEARCH METHODS

Groundwater bodies are defined spatially, geologically and hydrogeologically. The collected data were categorized and analyzed from the aspect of mineralogical composition of rocks, rock compaction, degree of rock mass cracking, porosity, content of organic components, carbonate content, content of clay components, content of metal oxide, pH value, redox potential, cation exchange capacity, cover thickness and degree of infiltration.

Also, the chemical properties of the soil itself through which the pollutant is infiltrated into the lithosphere, as well as the processes of biological, chemical and radiological degradation and hydrolysis processes, which support the pollutant or diminish its action, have also been considered. The characteristics of the aquifers were taken into consideration by the filtration coefficient and the hydraulic conductivity. The DRASTIC method was used to assess the vulnerability and the data are presented on a map in the scale of 1: 300 000 (Figure 4).

DRASTIC METODA is a acronym for:

D Depth to water table
R net Recharge
A Aquifer media
S Soil media
T Topography
I Impact of the vadose zone
C hydraulic Conductivity of the aquifer

The following conditions must be fulfilled for the DRASTIC method:
- the pollutant is introduced into the aquifer through the soil,
- the pollutant reached the aquifer by infiltration,
- the pollutant has the mobility of water,
- the study area is at least 0.4 km2.

Depth to groundwater level. Below the groundwater level all spaces and pores are filled with water. Above the groundwater, the pore spaces are partially filled with water and air. Water can be present in any type of medium, and it can be permanent or seasonal.

For the purposes of this paper, water depth refers to the depth to the water surface. In the case of confined aquifers, the saturated zones above the top of the aquifers were not considered separately. The depth to groundwater level is important because it determines the thickness of the material through which the pollutant must travel to the aquifer. Generally, there is a greater chance of degradation of the pollutant with increasing depth.

Table 2: Depth to groundwater rating

Depth to the groundwater (m)	
Range	Rating
0-1,5	10
1,5-4,5	9
4,5-9	7
9-15,25	5
15,25-23	3
23-30,5	2
30,5+	1

Table 3: Rainfall rating

Net recharge (cm)	
Range	Rating
0-5	1
5-10	3
10-18	6
18-25	8
25+	9

Net recharge (infiltration). The primary source of groundwater is precipitation, which infiltrates through the ground and enters the groundwater body. Net infiltration shows the amount of water per unit of land surface that penetrates the soil surface and reaches the groundwater. The infiltration can serve as a pollutant transporter perpendicular to the groundwater and horizontally within the aquifer. In addition, the amount of water in the unsaturated and saturated zone is also controlled by this parameter. In areas where the aquifer is in unconfined conditions, the recharge usually occurs more easily and the pollution is generally higher than in areas with confined aquifers. Confined aquifers are partially protected from harmful substances, which are introduced on low-permeability surface layers that slow the movement of water toward aquifers.

Table 4: Aquifer type rating

Massive shale	2
Metamorphic rocks	3
Weathered metamorphic rocks and thinlayered sandstones/ limestone	4
Layered shale	6
Massive sandstone	6
Massive limestone	6
Sand and gravel	8
Basalt	9
Karstified limestones	10

Tabele 5: Soil type rating

Soil type	
Loose or thin layered	10
Gravel	10
Sand	9
Peat	8
Shrinking/swalling clay	7
Sandy loam	6
Loam	5
Silty loam	4
Clayey loam	3
Mud	2
Non-shrinking/non-swelling clay	1

Aquifer type. Refers to consolidated or non-consolidated media that serve as an aquifer (such as sand and gravel or limestone). An aquifer is defined as a rock that will give a sufficient amount of water to use. Generally, larger grain size and more fractures or openings within the aquifer = greater permeability and therefore higher pollution potential (Table 4).

Type of soil. For the purpose of this paper, the soil is considered to be an upper spreading zone with an average thickness of two meters or less. Soil has a significant effect on infiltration and therefore on the ability to transfer pollutants perpendicular to the vadose zone. Furthermore, when the soil zone is quite thick, the processes of slowing down filtration, biodegradation, sorption and volatilization can be quite significant. In general, the pollution potential is mainly influenced by the type of clay, the shrink-swell capacity as well as the size of the grains. In general, the less the clay shrinks and swells and the smaller the grain size the less the potential for pollution. The present amount of organic materials in the soil can be an important factor (Table 5).

Table 6: Slope rating

Topography (% angle)	
0-2	10
2-6	9
6-12	5
12-18	3
18+	1

Topography. Topography refers to the slopes and angle of the surface. Topography helps to control pollutants in terms of the probability of their retention on the surface or the possibility of infiltration. Thus, the greater the possibility of infiltration and the greater the potential for pollution depend on the slope angle. The topography is significant from the point of view that the gradient and the flow direction can often be inferred for groundwater from a general soil slope. Usually, steeper slopes mean higher groundwater velocities.

Influence of unsaturated zone and hydraulic conductivity coefficient. The vadose zone is defined as the zone above the groundwater that is unsaturated. For the purpose of this paper, this strict definition can be applied to all groundwater aquifers. However, when evaluating confined aquifers, the "impact" on the vadose zone is extended to the vadose zone and all saturated zones lying above the aquifer. The vadose zone media types determine the characteristics of the soil material above the groundwater horizon. Biodegradability, neutralization, mechanical filtration, chemical reactions, volatilization and dispersion are processes that can occur within the vadose zone with general mitigation of the biodegradation and vaporization with depth. The media also controls the length of the route and the routing, thus affecting the degradation time and the amount of the pollutant.

Table 8 also shows the rating for the hydraulic conductivity coefficient within the aquifer, which implies that as the filtration rate increases, the rating value also increases, ie higher speeds have a negative impact on the protection of the water body (USGS, 1999).

Table 7: Unsaturated zone rating

Unsaturated zone impact	
Silt/clay	1
Slate	3
Limestone	6
Sandstone	6
Laminated limestones/sandstones/slates, sand and gravel with a high percentage of marl and clay component	6
Metamorphic rocks	4
Sand and gravel	8
Basalt	9
Karstified limestones	10

Table 8: Hydraulic conductivity rating

Hydraulic conductivity coefficient (m/day)	
0,004-4	1
4-12	2
12-28	4
28-40	6
40-81	8
81+	10

Table 9: Weight factor for the DRASTIC indeks calculation

Factor	Weight
Depth to the groundwater level	5
Net recharge	4
Aquifer type	3
Soil type	2
Topography	1
Vadose zone impact	5
Hydraulic conductivity coefficient	3

All DRASTIC factor weights were evaluated and relative values were assigned in the range of 1 to 5 (Table 9). The most significant factors have a value of 5 and the least significant 1. These weights are constant and cannot be changed.

The pollution potential indeks or the "DRASTIC index" is obtained by using the formula:

Pollution potential index = DR*DW + RR*RW + AR*AW + SR*SW + TR*TW+ IR*IW +CR*CW. Where the R represents the rating and W the vallue

RESEARCH RESULTS

A factor analysis was performed for each water body, based on the characteristics of the water bodies, numerical values from 1 to 10 were assigned for each individual factor and the pollution potential indeks was calculated (Table 10).

The resulting DRASTIC index values are presented numerically and graphically (Table 10, Figure 3), indicating the spatial distribution, as well as the DRASTIC values for each water body and the color code used to mark the DRASTIC index.

The Vulnerabilities of the groundwater bodies vary from 72 for the Misurići water body, to a maximum of 195 for the Kraševo water body. All water bodies with a low vulnerability index are at high depths or have a large thickness of roof insulators.

Table 10: DRASTIC index determination

No.	Name of the waterbody	D	R	A	S	T	I	C	DRASTIC index
1	Kladanj	1	6	10	5	1	4	10	120
2	Kladanj1	1	6	10	5	1	6	10	130
3	Krabašnica	1	8	10	5	1	4	10	128
4	Izron Suha-Zavidovići	5	9	8	5	1	4	10	146
5	Stupari	1	6	10	5	1	4	10	120
6	Gračanica-Živinice	3	1	10	5	1	6	10	120
7	Toplice	1	1	8	10	1	8	6	112
8	Sapna	1	6	6	3	1	6	8	108
9	Teočak	3	6	6	3	1	6	6	112
10	Miričina	2	9	6	5	9	6	8	137
11	Orahovica	7	9	8	5	9	6	10	174
12	Sklop, Soko, Seljanuša	3	6	6	5	5	6	10	132
13	Sjeverna Majevica 1	3	8	8	5	1	6	6	130
14	Sjeverna Majevica-Domažići	3	8	4	5	1	6	6	118
15	Mionica	5	8	6	5	3	4	4	120
16	Sprečko polje	1	9	8	10	10	1	6	118
17	Krekanski bazen	1	9	8	5	3	1	2	89
18	Spreča- Lukavac	1	9	8	10	10	1	2	106
19	Misurići	1	1	8	3	1	4	4	72
20	Havdine	5	9	8	10	10	6	4	157
21	Jelah	7	9	8	10	10	6	4	167
22	Kraševo	9	9	8	10	10	6	10	195
23	Gračanica 1	1	9	8	1	1	1	1	76
24	Čelić-Frigos	7	1	4	5	3	4	10	114
25	Okanovići- Gradačac	7	1	8	3	5	4	10	124
26	Odžak	9	9	8	9	1	1	2	135
27	Orašje- Domaljevac	9	9	8	9	1	8	6	182

In the study area, 27 water bodies were analyzed by the DRASTIC method. The water bodies of Gračanica 1 and Misurići have values below 79, while the water body of Kreka bassin has a value of 89 - which means that these water bodies are very well protected and the possibility of infiltration of the pollutants to aquifers is very small. The water bodies of Toplice, Sprečko polje, Teočak, Sapna, Čelić-Frigos and Sjeverna Majevica-Domažići have a range of values from 108-118 and belong to the group of protected water bodies, where the possibility of pollutant infiltration into the aquifer is present. The water bodies of Orahovica and Jelah belong to the group of highly vulnerable water bodies, where the possibility of pollutant infiltration into the aquifer is high. The water bodies of Orašje and Kraševo are water bodies without protection. Other water bodies belong to the group of medium vulnerable water bodies.

Obviously, the aquifer confinement plays the largest role in the water body protection. There is no protective overlay in the Kraševo water body, and the depth to the groundwater level is just two meters, while in the Misurići water body a large thickness of overlays is present and only recharge is done by the waters of the Bistrica river through absorbent wells, so the possibility of aquifer contamination is minimal.

CONCLUSION

Analyzing the groundwater bodies of northeastern Bosnia by the DRASTIC method, it was found that 50% of water bodies are with a medium vulnerability, 22% are with a low vulnerability, 11% without vulnerability and that 17% of water bodies have high to extreme vulnerability.

Some water bodies that are of karst - fractured porosity exhibit medium groundwater vulnerability values because they are trapped at relatively high depths, however, the lack of a protective overlay makes these water bodies very vulnerable. The first disadvantage of the DRASTIC method is that it is not suitable for water bodies of karst - fissure porosity, which lack a protective overlay. A PI or EPIK method is recommended for these water bodies, which takes into account the development of karst and epicarst. Another drawback of the DRASTIC method is the large amount of input parameters from which the vulnerability of water bodies is further calculated.

The DRASTIC method, unlike other methods, takes into account the slope of the terrain, the hydraulic conductivity coefficients, the soil - as a filtration medium and the geological composition of aquifers and layers above the water body. For this reason, the DRASTIC method yields the best results of groundwater vulnerability assessment in intergranular environments.

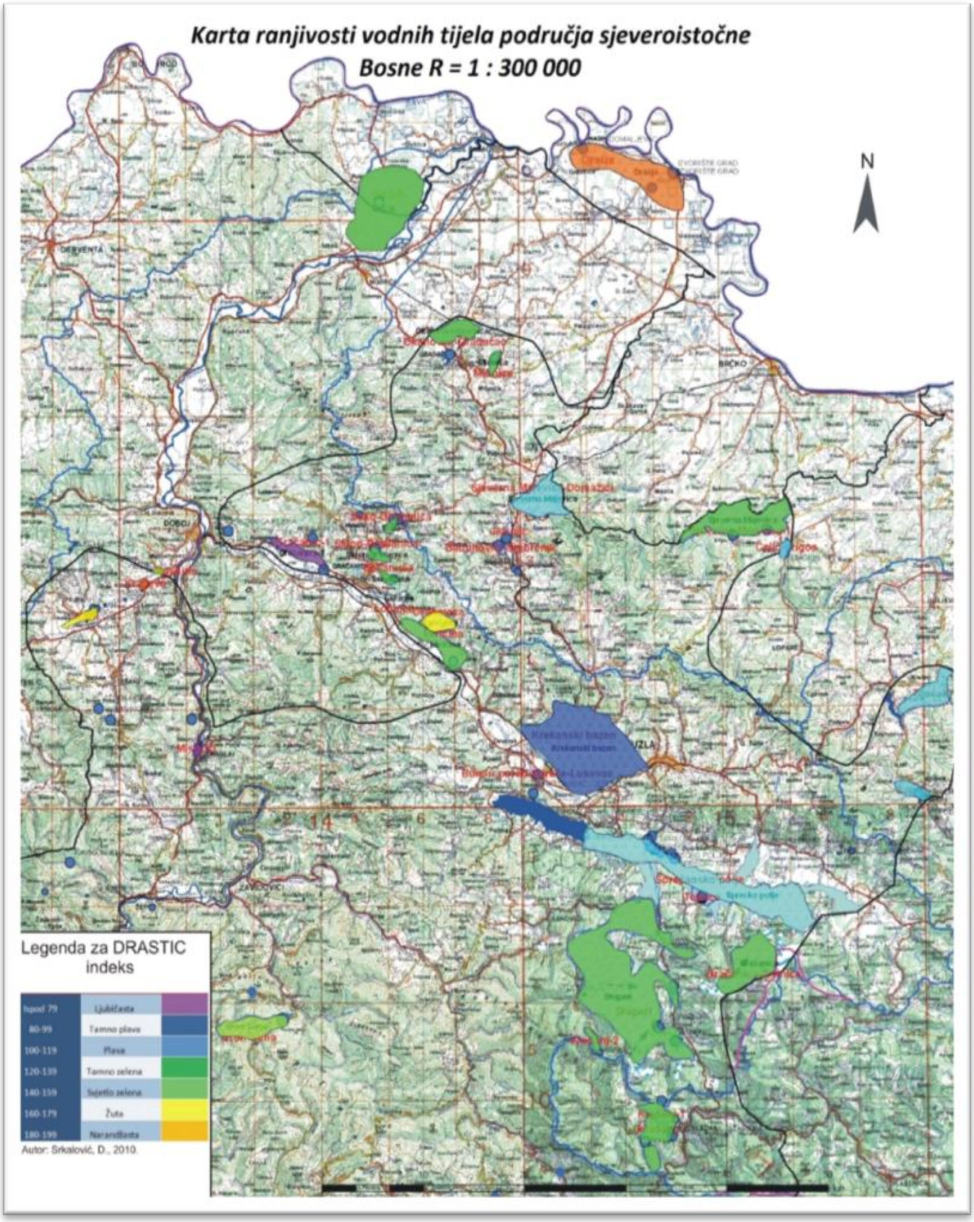

Fig. 4. Vulnerability of NE Bosnia groundwater bodies according to DRASTIC method

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Authors

Željka Stjepić Srkalović, master of geographical sciences, graduated at the Faculty of Sciences and Mathematics, University of Tuzla. Elected for senior associate assistant at the Faculty of Sciences and Mathematics, Geography Department in Tuzla, scientific field Physical geography. Author and coauthor of numerous scientific and professional papers published in scientific journals and one scientific book "Pedogeografija".

Dado Srkalović, PhD in geology **-** senior assistant at the Faculty of Mining, Geology and Civil engineering, University of Tuzla, Bosnia and Herzegovina. In 2017. defended PhD Thesis "Hydrochemical zoning of the groundwater bodies in northeastern Bosnia" at Geology Department of Faculty of Mining, Geology and Civil engineering, University of Tuzla. Author and coauthor of numerous scientific and technical articles.