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GROUNDWATER VULNERABILITY DETERMINATION OF NORTHEASTERN BOSNIA ACCORDING TO GLA METHOD

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SUMMARY

The paper assesses the vulnerability of 27 groundwater bodies in the basin of the river Bosna, ie 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 GLA method. For each water body, the determination of the effective soil capacity, degree of infiltration and rock type was made, as well as the final assessment of the protective efficiency of the unsaturated zones soil covering.

Key words: *groundwater bodies, groundwater, GLA method, map, northeast Bosnia, unsaturated zone, soil*

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 [1].

PHYSICAL-GEOGRAPHICAL POSITION OF NORTHEASTERN BOSNIA AND HERZEGOVINA

The exploration area is contoured by the rivers Sava in the north, Drina in the east, Bosna in the west and the rivers Drinjača and Krivaja in the south. The area covers about 6,350 km^2 and belongs to the most populated part of Bosnia and Herzegovina, Figure 1.

Northeastern 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.

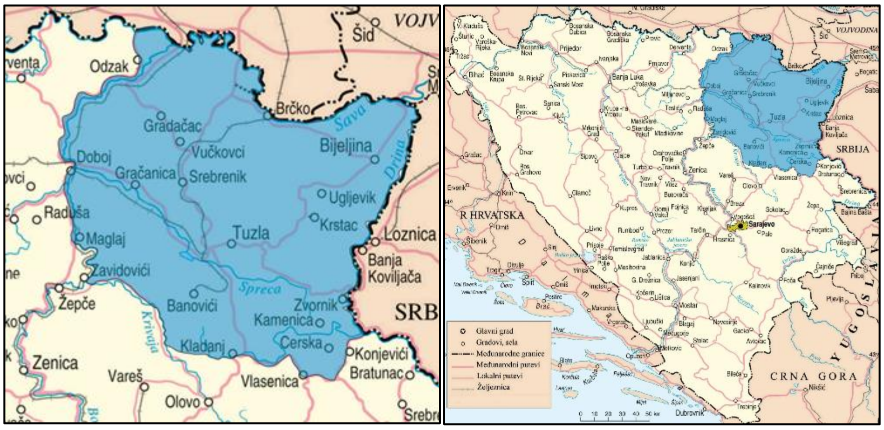

Figure 1. The geographic location of the examined area (edited by: Srkalović, D. 2015)

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, Figure 2. Northern of these flyschs the Inner Dinarides are extending, which can be divided into two zones [2]. 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 [3].

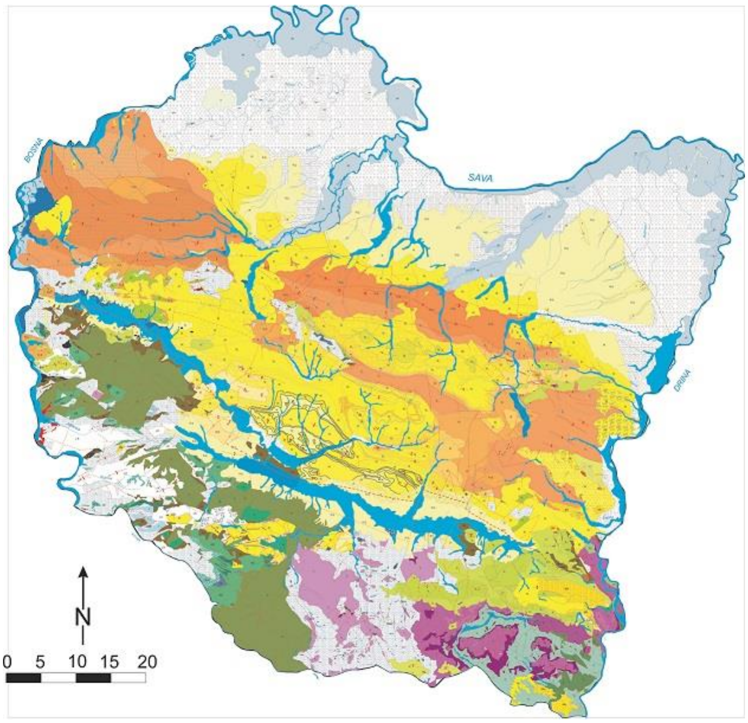

Figure 2. Geological map of northeastern Bosnia (scale 1:25,000) (Čičić, 2002, edited by: Srkalović, 2015)

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.

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 (100-500 km^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 [4,5,6,7].

The entire area of Semberia is located in the alluvial plane of the Drina River, with an elevation of 85-90 m 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 [8].

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 [9].

The largest river meanders are formed by lateral erosion of the Sava River, the biggest river flow in Bosnia and Herzegovina, whose mean annual flows downstream of the mouth of Bosnia exceed 1,000 m³/sec [10].

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 1,328 m.a.s.l., Ozren 918 m.a.s.l., Majevica 915 m.a.s.l. and Trebovac 692 m.a.s.l. [9].

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

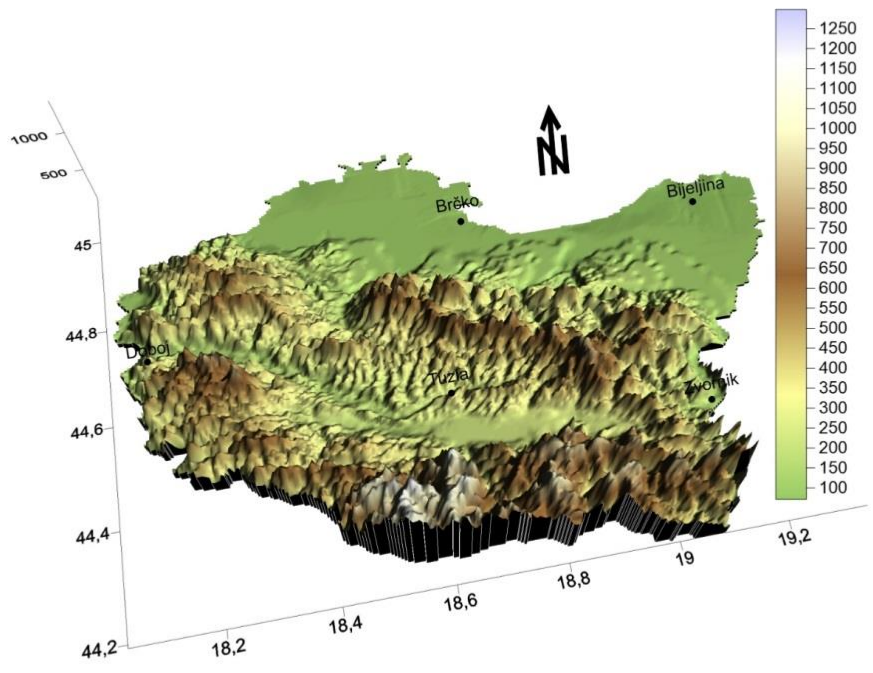

Figure 3. The relief of southeastern Bosnia (Srkalović, 2015.)

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. The average annual air temperature over Northeast Bosnia is 10.1°C and the average annual rainfall is 928 l/m^2 (Table 1).

Table 1. Average annual air temperature (°C), the rainfall amount (l/m^2), air humidity (%), cloudiness (1/10) and snow depth (cm) in North-eastern Bosnia

Meteorological station	Air temperature (°C)	Rainfall (l/m^2),	Humidity (%)	Cloudiness (1/10)	Snow cover (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
Northeastern Bosnia	10.1	928	80	5.8	84

Source: Federal hydrometeorological bureau Sarajevo, 2010.

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 values 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 [11].

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 [3]. 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 [12]. 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) [13].

The surface water 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 in 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 Herzegovina, 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% [14].

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 GLA method was used to assess the vulnerability and the data are presented on a map in the scale of 1: 300 000, Figure 4.

RESULTS AND DISCUSSION GLA METHOD

GLA method was first proposed by HOELTING et al. 1995 and is based on the summation of points in the system [16]. It was further developed into the PI method by Goldscheider in 2002. under the European COST 620 program, as it was found that the EPIK and GLA methods had certain shortcomings. The GLA method takes into account only unsaturated zones and the degree of vulnerability is determined by the protective effectiveness of the soils covering the unsaturated zones.

The following parameters were taken into account to assess the overall effectiveness of protection:

- S - Effective soil capacity,
- W - The infiltration degree,
- R - The type of rock,
- T - Soil and rock covering thickness above aquifer,
- Q - Bonus points for za purched aquifers,
- HP - Bonus points for hydraulic pressure (artessian conditions).

The total effective protection (P_T) is calculated by the formula:

P_1- effective protection covering $P_1 = S*W$

P_2- effective protection of unsaturated zone (sediments or hard rocks)

$$P_2 = W * (R_1*T_1+R_2*T_2+........R_n*T_n)$$

Effective soil capacity (S) (mm/dm) is determined for each horizon separately by field or laboratory measurements or it is determined from standardized tables such as e.g. AG Bodenkunde. It represents the amount of water that the soil can retain and that is used by plants. Organic components increase the value of water retention, while rock fragments decrease it. This value is multiplied by 10 decimetres of soil depth, because the soil depth of 10 decimeters is assumed to be up to the end of the roots. Table 2 shows the scoring for the soil type.

The total effective soil capacity (ΣeFC) is obtained by summing all the values for individual layers. The soil scoring based on effective soil capacity are shown in Table 3. Soil is a loose surface layer of the Earth's crust in which plants take root and where they take in nutrients, water and gases through their root system. By soil (pedological cover) we mean to scatter the surface layer of the Earth's crust, which, unlike massive rock, is characterized by fertility. This surface layer of the Earth's crust has changed and is constantly changing under the influence of atmospheric and biological factors [15].

Table 2. Effective soil capacity (source: Gupta, et.al., 1978)

Sand	15
Loamy sand	74
Sandy loam	121
Fine grained sand with loam	171
Very fine grained sand with loam	257
Loam	191
Silty loam	234
Silt	256
Sandy clayey loam	209
Silty clayey loam	204
Sandy clay	185
Silty clay	180
Clay	156

Table 3. Soil scoring based on effective soil capacity

ΣeFC	S
Up to depth (m)	
>250	750
200-250	500
140-200	250
90-140	125
50-90	50
<50	10

The degree of infiltration (W) is determined as the difference between the amount of annual precipitation and evapotranspiration. If we also have reliable data on the topography and composition of the terrain, the data are more accurate. Table 4 shows the scoring for the degree of infiltration.

Table 4. Scoring of the infiltration degree (factor W)

GWR (mm/year)	Factor W
<100	1,75
100-200	1,5
200-300	1,25
300-400	1,0
>400	0,75

The thickness of the rock mass takes into account all the thicknesses of the layers under the surface cover, ie. from 1m below the soil surface to groundwater levels. All types of rock masses are added and scored. Effective protection of rock mass below 1m of surface depends on several factors, which are:

Type of rock mass above the aquifer (R) With this parameter, consolidated and non-consolidated rocks are treated separately. In the case of unconsolidated rocks, the retention time of water within the rock mass is obtained from the cation exchange capacity (CEC), because it can be obtained directly from standardized lithological tables. Table 4 shows the R values for individual rocks.

If the rocks contain increased amounts of the organic component, 75 points are added to each meter of layer thickness. In the conditions of peat, unconsolidated volcanic material and sapropel, unlike the other rocks listed in Table 5, a high number of points was given due to the fact that these sediments have a high filtration rate.

Table 5. Division of unconsolidated rocks and scoring R

Type of unconsolidated rock	R_n
Clay	500
Low silty clay	400
Low sandy clay	350
Silty clay	320
Clayey loam	300
High silty clay, sandy clay	270
Silt with a high proportion of loam	250
Low clayey loam	240
Highly clayey silt, silty loam	220
High sandy clay, sandy silty loam, low sandy loam, silty loam, silty clay	200
Sandy loam, silt with a smaller share of loam	180
Silt with a smaller proportion of loam, silt with sandy loam	140
Sandy silt, sand with a high proportion of loam	120
Sand with loam, sand highly silty	90
Low clayey sand, silty sand, gravel with sand and clay	75
Sand with a small amount of clay, gravel with sand and silt	60
Low silty sand, sand with a smaller proportion of silt and gravel	50
Sands	25
Sand, gravely and gravel, sandy	10
Gravel, gravel and breccia	5
Unconsolidated volcanic material	200
Peat	400
Sapropel	300

When it comes to consolidated rocks, which generally have low permeability properties, it can be concluded based on cracks within the rocks and karstification that they have high permeability, and therefore low retention time of seepage water. For these reasons, the factor R is defined as the product of the factors O and F, where O stands for the type of rock, and F for the degree of cracking of the same. The values in Tables 6 and 6a refer exclusively to rocks that have not been exposed to the weather.

Table 6. Consolidation of consolidated rocks and scoring O

Rock type	O
Clay, shale, marl	20
Sandstone, quartzite, volcanic rocks, metamorphic rocks	15
Porous sandstone, porous volcanic rocks,	10
Conglomerates, breccias, limestones, gypsum	5

Table 6a. Rock structure scoring

Structure	F
No cracks	25,0
With fewer cracks	4,0
Medium number of cracks, weakly karstified	1,0
Moderately karstified	0,5

Large number of cracks, high karstification	0,3
Unknown	1,0

The thickness of the soil and rock mass above the aquifer (T) determines the time of water retention in rock masses, and thus the time in which water is exposed to mechanical, physico-chemical and microbiological effects.

Perched aquifers (Q) can reduce the migration of pollutants to greater depths, and thus reach the main aquifer. This protection is most effective where natural resources occur. With this factor, bonus points of 500 are added for each perched aquifer.

Aquifer pressure (HP) conditions depend on many factors, such as of the type of aquifer cover. If the aquifer is under pressure, 1500 points are added, for the reason that it is almost impossible for the pollutant to reach the aquifer, thus ensuring the low value of groundwater vulnerability.

Determination of the total protection effect

Values P_1 and P_2 are calculated separately. P_1 is the product of the total effective soil capacity (ΣeFC), which is taken from Table 2 and multiplied by the factor W from Table 3.

$$P_1 = S \text{ x } W$$

For P_2, which is the rock cover, the values for each layer are calculated individually, taking the values from Table 4 or 5, depending on the type of rock and multiplying the values by the thickness in meters (factor T). The sum of all values, taking from 1m and below represents an effective protection of the rock cover under the ground. These values are also multiplied by a factor of W, which represents the degree of seepage.

If there are, bonus points are added for perched aquifers with springs and aquifers that are under pressure.

$$P_2 = W \text{ x } (R_1xT_1+R_2xT_2+....+R_nxT_n)+Q+HP$$

The effective protection factor is obtained as a sum of P_1 and P_2.

$$P_t = P_1+P_2$$

Table 7 shows 5 classes of effective aquifer protection, which are based on the coefficients shown above and the retention time of water in the soil and rock above the aquifer.

Table 7. Rating of GLA vulnerability method of groundwater bodies

Overall effective protection	Total number of points P_t	Retention time of water (pollutants) in the soil / rock above the aquifer
Very high	>4000	>25 years
High	2000-4000	10-25 years
Moderate	1000-2000	3-10 years
Low	500-1000	Few months to 3 years
Very low	<500	Few days to 1 year, in karst terrains often less

RESULTS

Table AG Bodenkunde – (AG Bodenkunde: Bodenkundliche Kartieranleitung, Hrsg. Arbeitsgemeinschaft Bodenkunde der Geologischen Landesämter und der Bundesanstalt für Rohstoffe- Tabelle 1-6a) was used for the GLA method as well as for the effective soil capacity.

It is noticeable that groundwater bodies of Havdine, Jelah and Kraševo have extremely small values of effective soil capacity (S), which can be explained by the relatively shallow groundwater level as well as the characteristics and thickness of the soil above the water body. Based on Table 8, the calculation for P_1 and P_2 was performed according to the existing formulas, and if there is a barrage of aquifers, bonus points are added. The obtained data are shown in Table 9.

Table 8. Parameter values for calculating vulnerability by GLA method

No.	*Name*	*S*	*W*	*R_n / O*	*F*	*HP/Q*
1	Kladanj	750	1,5	15	0,3	-
2	Kladanj1	500	1,5	15	-	-
3	Krabašnica	750	1,25	15	0,3	-
4	Izron Suha-Zavidovići	750	1,20	15	1,0	-
5	Stupari	750	1,5	10	-	-
6	Gračanica-Živinice	750	1,75	15	0,3	-
7	Toplice	750	1,75	25	-	1500
8	Sapna	750	1,5	20	0,5	1500
9	Teočak	750	1,5	5	0,5	-
10	Miričina	750	1,20	75	-	1500
11	Orahovica	750	1,20	75	-	1500
12	Sklop, Soko, Seljanuša	750	1,5	75	-	-
13	Sjeverna Majevica 1	500	1,25	25	-	-
14	Sjeverna Majevica-Domažići	500	1,25	20	0,3	1500
15	Mionica	750	1,25	20	0,3	1000
16	Sprečko polje	750	1,20	200	-	1500
17	Krekanski bazen	750	1,20	500	-	1500+2000
18	Spreča- Lukavac	750	1,20	200	-	1500
19	Misurići	750	1,75	50	-	-
20	Havdine	10	1,20	5	1,0	-
21	Jelah	10	1,20	75	-	-
22	Kraševo	10	1,20	20	1,0	-
23	Gračanica 1	250	1,20	500	-	1500
24	Čelić-Frigos	500	1,75	15	1,0	-
25	Okanovići- Gradačac	750	1,75	10	-	-
26	Odžak	125	1,20	500	-	1000
27	Orašje- Domaljevac	750	1,20	350	-	1500

Table 9. Values of GLA index

No.	*Name*	*P_1= S x W*	*P_2*	*Bonus points*	*P_T*
1	Kladanj	1125	2250	-	3375
2	Kladanj1	750	6750	-	7500
3	Krabašnica	937,5	5625	-	6562,5
4	Izron Suha-Zavidovići	900	2700	-	3600
5	Stupari	1125	4500	-	5625
6	Gračanica-Živinice	1312,5	2625		3937,5
7	Toplice	1312,5	8750	1500	11562,5
8	Sapna	1125	690	1500	3315
9	Teočak	1125	675	-	1800
10	Miričina	900	2430	1500	4830
11	Orahovica	900	810	1500	3210
12	Sklop, Soko, Seljanuša	1125	7875	-	9000
13	Sjeverna Majevica 1	625	1562,5	-	2187,5
14	Sjeverna Majevica-Domažići	625	3750	1500	5875
15	Mionica	937,5	250	1000	2187,5
16	Sprečko polje	900	50400	1500	52800
17	Krekanski bazen	900	60000	3500	64400
18	Spreča- Lukavac	900	52800	1500	55200
19	Misurići	1312,5	4375	-	5687,5

20	Havdine	12	60	-	72
21	Jelah	12	810	-	822
22	Kraševo	12	72	-	84
23	Gračanica 1	300	36000	1500	37800
24	Čelić-Frigos	875	157,5	-	1032,5
25	Okanovići- Gradačac	1312,5	157,5	-	1470
26	Odžak	150	39000	1000	40150
27	Orašje- Domaljevac	900	2100	1500	4500

Based on the obtained values of the GLA index, a map of effective protection of water bodies was made, Figure 4.

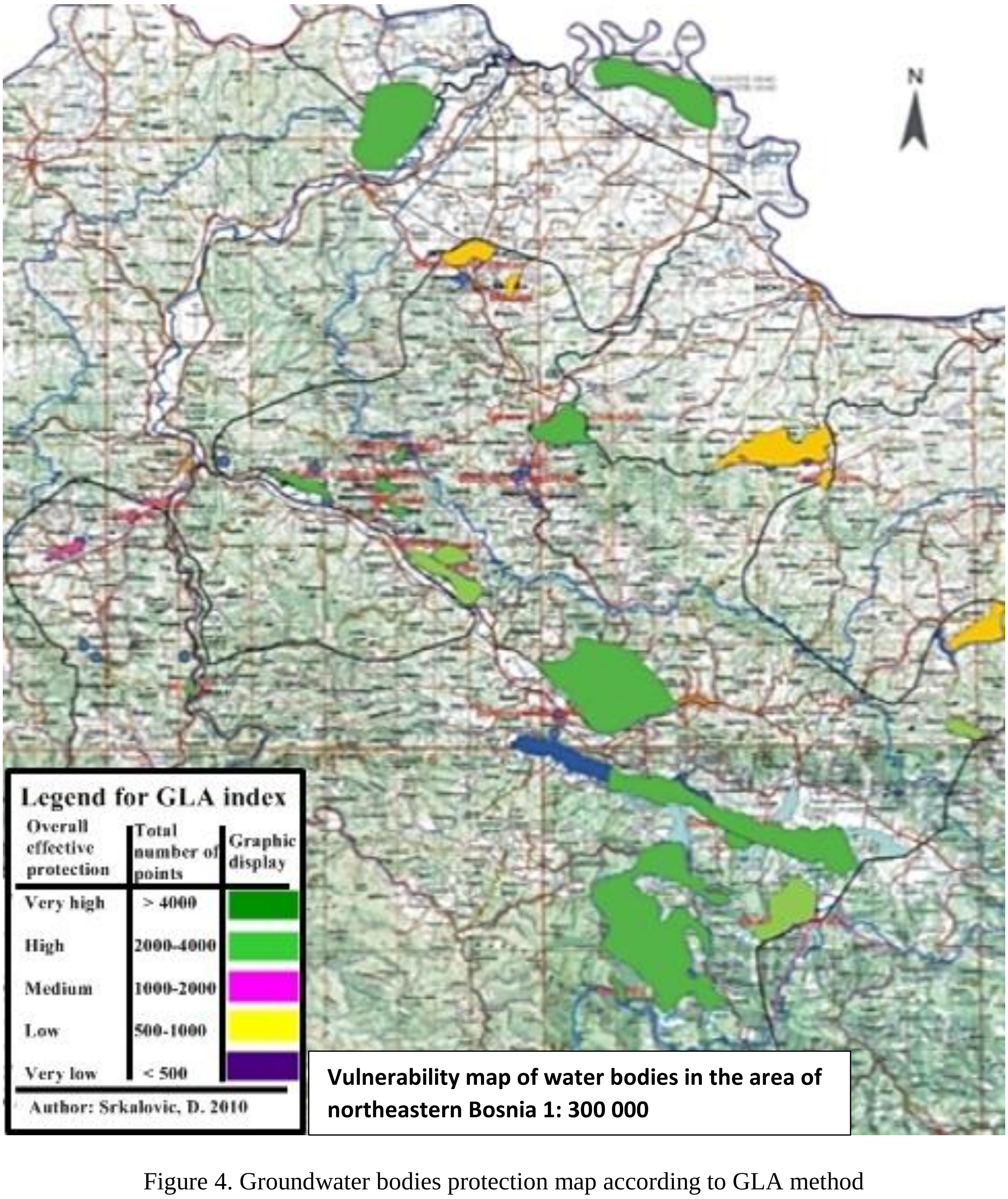

Figure 4. Groundwater bodies protection map according to GLA method

The values of groundwater body protection vary from 72 for the Havdine water body to 64400 for the Kreka basin water body. Of the 27 analyzed water bodies, 19 are with high and very high protection factor, 5 with medium protection factor and 3 with low (Havdine, Jelah and Kraševo).

The greater the thickness of the soil above the water body and the more heterogeneous the soil, the higher the value of protection - as is the case with the Krekan basin, Sprečko polje and the water body

Domaljevac. In the water bodies of Havdine, Jelah and Kraševo, the thickness of the cover is on average 2 meters, which is also of sand-gravel composition, so that the protective function is completely absent.

CONCLUSION

The GLA method gives the best results for water bodies where there is soil as a filtration medium and a large thickness of the protective layer. It is very similar to the DRASTIC method and the results in most cases coincide with the results obtained by the DRASTIC method, with a much smaller amount of data required, as well as data for the aquifer itself and the filtration rate are not required.

The paper evaluates the groundwater bodies of Northeast Bosnia by the GLA method. Water bodies of intergranular, fissure and karst-fissure porosity are present in this area. Most of the analyzed water bodies show high values of protection factor, while a small part belongs to the group of medium and low protection factor. Each water body requires a different approach and a different method for assessing vulnerability. It is impossible to obtain true vulnerability data for multiple different water bodies by a single method. Groundwater bodies, located in the southern part of the study area and treated by the GLA method, show very good values from the aspect of protection, however, since they are found in limestones, which are cracked and where the thickness of the cover is very small or missing in completely, these results should be taken with a reserve and ultimately compared with another method - preferably the EPIK method.

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