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## THE VULNERABILITY DETERMINATION OF GROUNDWATER BODIES IN SOUTHEASTERN BOSNIA ACCORDING TO DRASTIC, GLA AND EPIK METHODS

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### SUMMARY

The vulnerability results of groundwaterbodies of southeastern Bosnia are shown in this paper. On the examined area 27 groundwater bodies were extracted, where 12 groundwaterbodies are in rocks with intergranular porosity and 15 groundwaterbodies are in rocks with karst-fissure porosity. All of the groundwater bodies were analysed through DRASTIC, GLA, PI and EPIK vulnerability determination methods, where the gained results are presented tabular. Depending on the porosity type, the vulnerability determination methods were used. So for intergranular groundwaterbodies the best results were gained by DRASTIC and GLA methods, while for the karst-fissure groundwater bodies the best results were gained by the EPIK method, which is the implementation of PI method.

Key words: *groundwater bodies, southeastern Bosnia, drastic, gla, epik, vulnerability*

### THE GEOGRAPHIC LOCATION OF THE EXAMINED AREA

The investigated area is contoured by its administrative, cantonal and geomorphological borders, so it is contoured on the north by Brčko, Orašje, Šamac, and Bosanski Brod, on the south by Vlasenica, Kladanj, and Žepče, on the east by Bijeljina, Janja, and Zvornik, and on the west by Zavidovići, Teslić, Derventa, and Bosanski Brod. The examined area is on 8.000 km<sup>2</sup>. The area belongs to the part of the country with the highest population density, so the population is one of the main factors which can lead to the groundwater pollution.



Picture No. 1. The geographic location of the examined area (Srkalović D. 2010)

## GEOLOGICAL AND HYDROGEOLOGICAL CHARACTERISTICS OF THE EXAMINED AREA

The terrains which belong to the investigated area of southeastern Bosnia are in the middle and inner Dinarides. Looking from the south in the inner Dinarides a zone of paleozoic slates and mesozoic limestones are separated, following the Zenica-Sarajevo basin, and a zone of jurassic-cretaceous and uppercretaceous flysch. The inner Dinarides can be divided into two zones. The first zone is the central ofiolithic zone, which is intersected by the Bosna river on the profile which begins 5 kilometers northern from Vranduk, and ends in the Doboj area. Northern from Doboj to the Sava river the horst and graben formations are crossed by the Bosna river [1].

Every of the named zones are characterised by certain formations and tectonical units, which have an impact on the waterbodies. The zone of paleozoic slates and mesozoic limestones is located in the upper part of Bosna river.

This zone is made of various slates, sandstones, limestones and dolomites, with appearance of volcanic rock formations, with riolithes as the dominant ones. The border between these two zones is the Busovača fault zone. In the tectonical view, the area belongs to the zone of inner paleozoicum, ofiolithic zone and the zone of paleozoic slates and mesozoic limestones (small area of the Sutjeska belongs to the zone of high karst). The tectonics is represented by intensive foldings, cracking and horizontal movements of the masses, block sinkage, interruption in sedimentation, etc. A zone of paleozoicum, mesozoicum and cenozoicum formations has been separated, which have a northwest-southeast direction.

The northwestern part of the central Bosnian slates and mesozoic limestones are mainly made of the Vlašić mountain limestones and dolomites [1], with the springs Plava voda 960 l/s, Bašbunar 80 l/s, Hendek, 15 l/s and Šantići [2]. Higher capacity accumulations are in the separated triassic deposits of Zvijezda, Javor, Romanija, Ozren and Konjuh mountain limestones, as well the Gostelja river waterbasin, southern from the Sprečko Polje. Near Doboj, on the left and right sides of Bosna river, a hydrogeological aquifer of karst-fissure porosity has been discovered [3,4]. Along the northeastern border of the Zenica-Sarajevo basin, a Kraljeva Sutjeska spring with 12 l/s, Toplik, Ilidža-Ribnica 40 l/s and Bioštica are appearing.

In the Spreča river waterbasin, in the Gostelja river spring area, two separate accumulations in the middle and upper triassic limestones were formed with springs Tarevčica, Zatoča, Sedam Vrela and Toplica, catched for the Tuzla watersupply. For the Banovići watersupply, a Studešnica spring is catched. The serpentinites and peridotites represent the bottom isolators, waterunpermeable rocks, intersected with cracks. The middletriassic limestones has been developed in the seperated zones by Brateljevići, Turalići and Dragušā. In the lower terrains at the contact between the waterunpermeable rocks and limestones, an occasional or permanent springs are appearing. (Brateljevići, Kladanj, Bjelašnica) [5].

In the waterbasin of Drina river, three kinds of watershed are developed: the surficial one (orographical), underground (hydrogeological) and zonal (hydrogeological). The surface watershed intersects the terrain parts where the lithological composition and the formation bedding do not allow the penetration of groundwater into the deeper layers of the terrain. That are the terrains built of waterunpermeable formations of verfene, paleozoicum, volcanic-sediment formations and ultramafites. The underground hydrogeological watershed stretches at the area where the surface and underground watersheds are not overlapping, or the underground one is deep enough, and by colour tracing techniques a prove has been given that these water are flowing into a defined direction. The underground zonal watershed separates certain waterbasin parts at two or more waterbasins, and during the time the border moves on one or the other side, depending on the aquifer level.

The Drinjača river waterbasin (springs Tišća and Studeni Jadar) collects water from several springs from the carbonate massive of Udrč and Kladanj surroundings. The carbonate complex of the upper

part of Drinjača have separated groundwater accumulations. The groundwater are draining on the springs in Brateljevići, Podpauč, Plahovići, Stanići, Plazače and Lovnica. In the wider area of Kladanj, the most significant springs Podpauč, Pećina and Plahovići. The biggest accumulation is draining from the Veliki Bratnik ( $Q_{min}=20$  l/s). From the Javornik mountain water is draining into the Drinjača river from springs Kulješim ( $Q_{min}=25$  l/s), Bjelašnica ( $Q_{min}=40$  l/s) and Lovnica ( $Q_{min}=10$  l/s).

The Drina waterbasin groundwater reserves are calculated by 4414 l/s. From these reserves about 80% are in C<sub>1</sub> category, while the reserves A and B are about 20%. The low level of aquifer investigation does not allow the transition of groundwater reserves into higher categories [6].

**GROUNDWATER BODIES DETERMINATION**

The groundwater bodies in karst-fissure and intergranular media were extracted. In the karst-fissure media are units which are in limestone complex of „outer Dinarides“ carbonate platform, massive layered limestones, partly with dolomites, marly thinlayered limestones, marbles, dolomite limestones, limestone conglomerates and breccia and neogene limestones with low part of sandstone inclusions.

The waterbodies in karst-fissure media are more complex and less investigated as the intergranular ones. The groundwaterflow mechanism is very complex for each one waterbody, so the flow direction can be estimated only by colour tracing techniques. The capacities of these waterbodies are depending by the hydrogeological conditions, so the minimum and maximum capacity differences can be very big. The spring draining mechanism is the mainly „contact type“, where the contact is represented by limestones and waterunpermeable clastic formations of paleosoicum, mesosoicum and cenosoicum age. In table No.1 the groundwater bodies of karst-fissure porosity are shown.

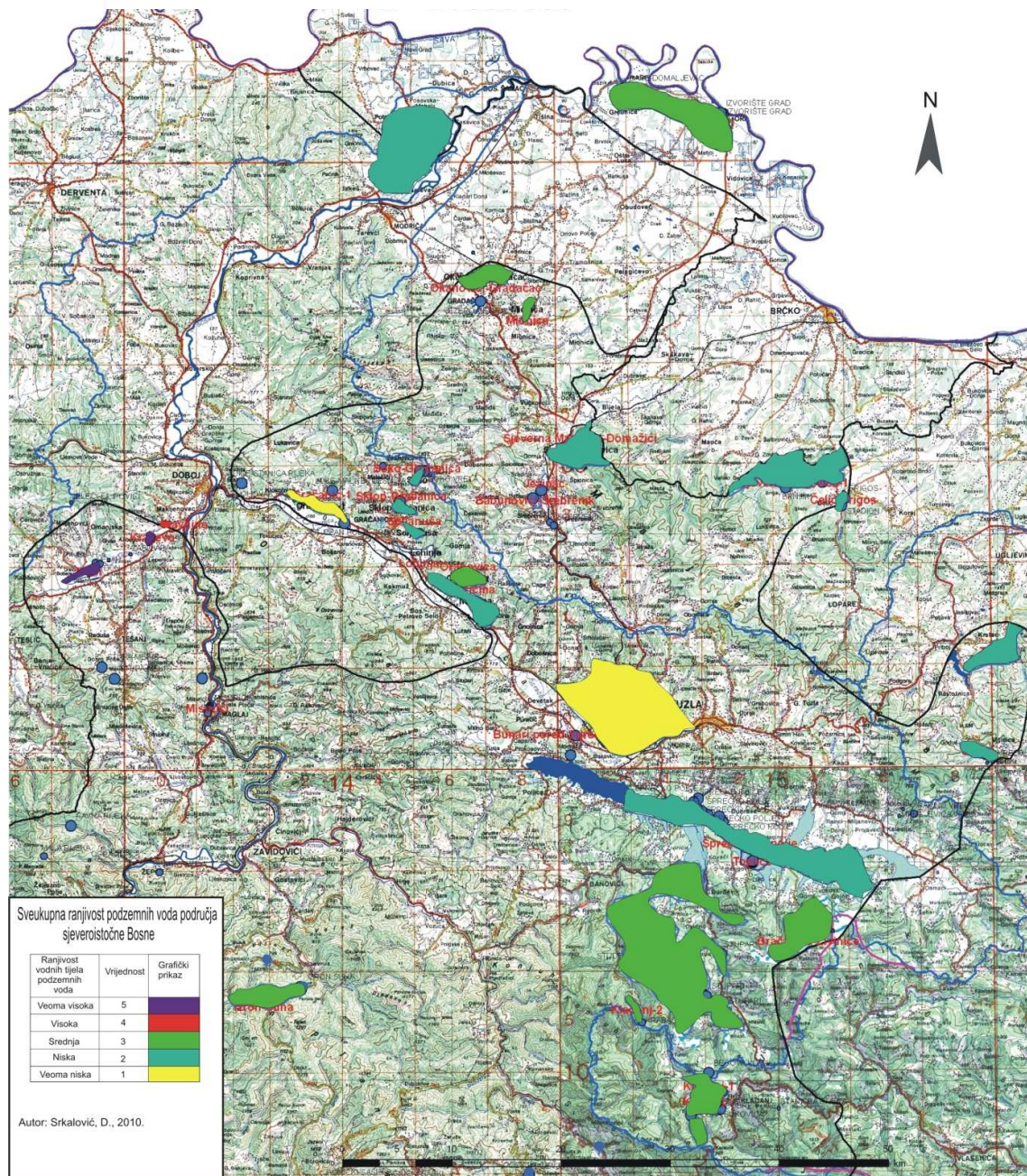
Table No. 1

<b>Name of waterbody with karst-fissure porosity</b>
Kladanj
Kladanj1
Krabašnica
Izron Suha-Zavidovići
Stupari
Gračanica-Živinice
Toplice
Sapna
Teočak
Miričina
Orahovica
Sklop, Soko, Seljanuša
Sjeverna Majeвица 1
Sjeverna Majeвица-Domažići
Mionica

Table No. 2

<b>Name of waterbody with intergranular porosity</b>
Sprečko polje
Krekanski bazen
Spreča- Lukavac
Misurići
Havdine
Jelah
Kraševo
Gračanica 1
Čelić-Frigos
Okanovići- Gradačac
Odžak
Orašje- Domaljevac

The intergranular porosity groundwater bodies are characterised by relatively simple mechanism of intake recharge, and by a clear movement mechanism, so that these waterbodies are well investigated, in term of geology and the dominant flow directions. The dominant flow directions are depending from the hydrological condition of contour recipients. In table No.2 the groundwater bodies with intergranular porosity are given. Intergranular and karst-fissure groundwaterbodies situation is shown in picture No.2 [7, 8, 9, 10, 11, 12, 13].



Picture No. 2. Groundwaterbodies of the examined area with the data of aggregative vulnerability

### VULNERABILITY DETERMINATION OF GROUNDWATER BODIES

Every groundwater body has been processed by DRASTIC, GLA and EPIK methods. The best results for intergranular unconfined groundwater bodies are gained by the DRASTIC method, for confined groundwater bodies the GLA method is suitable and for the karst-fissure porosity the EPIC method is the most suitable one [2]. The gained values by these three methods are given in tables 3, 4 and 5.

Table No. 3- DRASTIC index values

Ordinal number	Groundwater-body name	DRASTIC index
1	Kladanj	120
2	Kladanj1	130
3	Krabašnica	128
4	Izron Suha-Zavidovići	146
5	Stupari	120
6	Gračanica-Živinice	120
7	Toplice	112
8	Sapna	108
9	Teočak	112
10	Miričina	137
11	Orahovica	174
12	Sklop, Soko, Seljanuša	132
13	Sjeverna Majeвица 1	130
14	Sjeverna Majeвица-Domažići	118
15	Mionica	120
16	Sprečko polje	118
17	Krekanski bazen	89
18	Spreča-Lukavac	106
19	Misurići	72
20	Havdine	157
21	Jelah	167
22	Kraševo	195
23	Gračanica 1	76
24	Čelić-Frigos	114
25	Okanovići-Gradačac	124
26	Odžak	135
27	Orašje-Domaljevac	182

Table No. 4 – The GLA index values of overall effective groundwater bodies protection

Ordinal number	Groundwaterbody name	$P_r$
1	Kladanj	3375
2	Kladanj1	7500
3	Krabašnica	6562,5
4	Izron Suha-Zavidovići	3600
5	Stupari	5625
6	Gračanica-Živinice	3937,5
7	Toplice	11562,5
8	Sapna	3315
9	Teočak	1800
10	Miričina	4830
11	Orahovica	3210
12	Sklop, Soko, Seljanuša	9000
13	Sjeverna Majeвица 1	2187,5
14	Sjeverna Majeвица-Domažići	5875
15	Mionica	2187,5
16	Sprečko polje	52800
17	Krekanski bazen	64400
18	Spreča- Lukavac	55200
19	Misurići	5687,5
20	Havdine	72
21	Jelah	822
22	Kraševo	84
23	Gračanica 1	37800
24	Čelić-Frigos	1032,5
25	Okanovići- Gradačac	1470
26	Odžak	40150
27	Orašje- Domaljevac	4500

From the table No.3 it can be seen that the values are in range from <79 to 195, where 79 is representing an insignificant vulnerability of groundwater, and the value 199 is representing an extreme vulnerability of groundwater.

The GLA method does not treat the vulnerability of groundwater, it treats the overall effective protection of groundwater bodies, so that the higher values are representing a higher protection and a lower risk for contamination of groundwater bodies [9]. In table No.4 the GLA index values are given.

The GLA index values are in range from <500 for very low effective protection to >4000 for a very high effective protection. From the table No.4 it can be seen that the values for the effective protection are proportionally reversible to the DRASTIC index values from the table No.3. So for example the waterbody Havdine has a very low effective protection and a very high vulnerability. It can also be seen that the waterbodies Havdine, Jelah and Kraševo are with very low effective protection indexes,

what can be explained by shallow bedding of the waterbodies and a absence of aquifer protective covering formations [2]. Like the GLA method the EPIK method determines the protective index of groundwater bodies, but unlike the GLA method, this one determines the protection index of karst-fissure groundwater bodies. The results are shown in table No.5.

Table No. 5 – EPIK index values for karst-fissure groundwater bodies

Groundwaterbody name	Protection index
Kladanj	16
Kladanj1	16
Krabašnica	10
Izron-Suha Zavidovići	14
Stupari	10
Gračanica-Živinice	17
Sapna	29
Teočak	26
Miričina	32
Orahovica	23
Sklop, Soko, Seljanuša	26

The values are in range from 9, which represent low protective characteristics to 34 which represent high protective characteristics of groundwater bodies. From the table No.5 it can be seen that karst-fissure porosity groundwater bodies on the investigated area are either high vulnerable waterbodies (9-19) or waterbodies with no vulnerability (26-34), with the exception of Orahovica waterbody, which has a value of moderate vulnerability.

## CONCLUSION

Analysing the above described vulnerability determination methods and synthetising the gained data, a conclusion can be made that:

The groundwater bodies Kladanj, Kladanj 1, Krabašnica, Izron - Suha, Stupari and Gračanica - Živinice according the EPIK method have a high vulnerability, because of intensive karstification processes. The waterbodies Orahovica and Orašje – Domaljevac have a very high vulnerability according the DRASTIC method, while according to the other methods they have low to very low vulnerability. A explanation is that the DRASTIC method takes in calculation the inclination of slopes and hydraulic conductivity, which significance is very high.

The waterbodies Jelah, Havdine and Kraševo have a high vulnerability according to all methods, what is the result of shallow aquifer bedding and permeable covering formations.

The waterbodies Toplice, Sjeverna Majevisa – Domažići, Sprečko polje, Krekanski bazen, Misurići and Gračanica 1 have a very low vulnerability, what is the result of thick unpermeable covering formations and a deep bedding of the aquifer.

A conclusion can also be made, that the waterbodies which are in the area of industrial zones and which are in plain regions are more vulnerable from those in the hilly areas, except the ones where the karstification processes are intensive.

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