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SPRINGS IN THE ŽUMBERAK – SAMOBORSKO GORJE NATURE PARK

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This paper presents the results of fundamental hydrogeological research of springs in the Žumberak – Samoborsko gorje Nature Park during the period 2007–2008. The research resulted in 847 recorded springs whose basic physicochemical parameters and discharge were measured *in situ* at least once. Distribution of springs by lithostratigraphic units and altitude are analyzed. Spring discharge distribution and their basic physicochemical parameters are presented.

Keywords: springs, distribution, lithostratigraphic units, altitude, discharge, hydrochemistry, Žumberak, Samoborsko gorje, Nature Park

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Rad donosi rezultate temeljnog hidrogeološkog istraživanja izvora u Parku prirode »Žumberak – Samoborsko gorje« tijekom perioda 2007.–2008. godine. Istraživanje je rezultiralo s 847 kartiranih izvora kojima su *in situ* najmanje jedanput izmjereni osnovni fizikalno – kemijski parametri i izdašnost. Analizirana je raspodjela izvora prema litostratigrafskim jedinicama te nadmorskoj visini. Raspodjela izdašnosti izvora i njihovi osnovni fizikalno – kemijski parametri su prikazani.

Ključne riječi: izvori, raspodjela, litostratigrafske jedinice, nadmorska visina, izdašnost, hidrokemija, Žumberak, Samoborsko gorje, Park prirode

INTRODUCTION

The Žumberak – Samoborsko gorje Nature Park is a protected carbonate mountainous massif in the central western part of Croatia next to the border with Slovenia (Fig. 1). It covers 342.52 km^2, rising from 180 to 1178 m a. s. l., with the highest peak of Sveta Gera.

Climate is characterized by mean annual temperature of between 6 °C in the highest mountain parts and 11 °C in the lowest south eastern parts of the Park (ZANINOVIĆ *et al.*, 2004). Annual mean air temperature of January varies from –1 °C

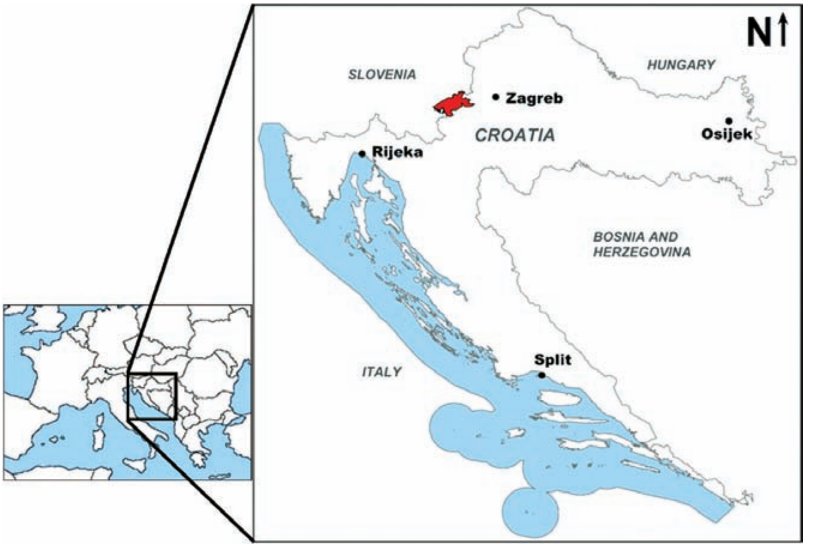


Fig. 1. Žumberak – Samoborsko gorje Nature Park is red marked in the central western part of Croatia.

to less than –2 °C in the highest parts, and the mean annual air temperature in July varies from 20 °C to less than 18 °C in the highest parts. The highest precipitation occurs in June and October, and the lowest in March with an average annual precipitation between 1100 and 1700 mm.

The Nature Park is characterized by fluviokarst and karst morphological with small karstification depth. There are numerous karst morphological forms – dolines, blind and dry valleys, caves, shafts and hydrogeological features – underground circulation with ponors and karst springs (BOČIĆ & BUZJAK, 1998).

Geological and hydrogeological research of the Samoborsko gorje and Žumberak have been conducted over a number of years, but this was the first hydrogeological study that approached this complex karst terrain as a whole. Many authors recently conducted fundamental hydrogeological studies (GOLDSCHEIDER & NEUKUM, 2010; HICKEY, 2010; RAVBAR & KOVAČIČ, 2010) that showed their importance and benefits in the characterization of karst aquifers. The basis of this research was a hydrogeological study by BRKIĆ *et al*. (2002) that provided basic information on the hydrogeological characteristics of the area including 344 registered springs.

Due to the geological complexity, size and indented nature of this area, but also considering the knowledge of the terrain, it was hypothesised that there were many more springs. The aim of this fundamental hydrogeological research was to inventory all the springs in the Park, recording, measuring and analyzing their basic characteristics. The main part of this study was carried out from 10.4.2007. to 15.3.2008. It resulted in the registration of 847 springs whose basic physicochemical parameters (temperature, pH, electrolytic conductivity, total dissolved solids, oxygen concentration) and discharge in situ were measured at least once. Distribution of springs by lithostratigraphic units and altitude are analyzed and presented. Their discharge and basic physicochemical parameters are presented only as possible aquifers indicators.

Geological and hydrogeological settings of the studied area

The study area is characterized by a very intricate geological structure originating from dynamic geotectonic movements during the geological past. Rocks of different petrographic composition and lithological features emerged because of the changes in temporal and spatial conditions. Intensive geotectonic activity is visible through frequent changes in the vertical and horizontal sequence of deposits.

The geological structure of the terrain is dominated by sedimentary rocks ranging stratigraphically from Carboniferous – Permian (C,P) to Quarternary (Q) Ages (BUKOVAC *et al.*, 1983; BUKOVAC *et al.*, 1984; PLENIČAR *et al.*, 1975; PLENIČAR & PREMRU, 1977; ŠIKIĆ *et al.*, 1977; ŠIKIĆ *et al.*, 1979.). The largest part of Žumberak is covered by Upper Triassic (T_3) deposits, dominated by dolomites, and Upper Cretaceous deposits (K_2) in the form of carbonate – clastic flysch and limestones. Due to its predominantly carbonate structure, this terrain tends to karstification.

Hydrogeological characteristics of studied area are presented according to rock type, their porosity and permeability, surface rock deformation degree, and water and morphologic features. The rocks are divided at five groups as follows:

1. Unconsolidated Quarternary deposits
   a. highly permeable
   b. very low permeable
2. Unconsolidated Plioquarternary deposits
   a. low permeable
3. Carbonate rocks
   a. highly permeable
   b. medium permeable
   c. low permeable
4. Interchange of clastic rocks, or clastic and carbonate rocks
   a. low permeable
5. Magmatic and other clastic rocks
   a. impervious

Unconsolidated Quarternary deposits are represented by stream alluvial sediments and terra rossa. Alluvial deposits are composed of gravel, sand, silt, clay, and their combinations and interchanges. Their intergranular porosity makes them highly permeable. The thickness of the alluvial aquifer is up to six meters at Krašić in the Park's vicinity, with hydraulic conductivity of 244.5 m/day (DRAGIČEVIĆ *et al.*, 1997). Terra rossa deposits are restricted to small areas of the Park, they have intergranular porosity and very low permeability.

Unconsolidated Plioquarternary deposits can be found in small areas of the researched terrain. They are composed of gravel, sand, silt, clay, and their combinations and interchanges. It gives them intergranular porosity and low permeability.

Carbonate rocks cover the largest part of the Park and have fissure or karst porosity. Their permeability is directed by the lithological composition and intensity of tectonic deformations, which divide them at three subgroups. Highly permeable carbonate rocks are karstified Badennian lithothamnium limestones, Cretaceous calcareous breccias, Jurassic limestones and highly fractured Upper Triassic dolomites. Upper Triassic dolomites make up the main aquifer of researched terrain, which also includes the most important springs. Medium permeable carbonate rocks are Jurassic dolomites and Middle Triassic dolomites. Low permeable carbonate rocks are Permian limestones and dolomites that contain thin beds of shale.

Interchange of clastic rocks or clastic and carbonate rocks occur at the areas covered by Pannonian calcareous or argillaceous marls, Paleocene calcareous breccias, Upper Cretaceous carbonate – clastic flysch. They have intergranular, fissure or karst porosity, which is directed by a change of their lithological composition. Impervious strata dominate within these rocks so they are considered low permeable. However, limestone sequences within them can be quite permeable as seen by 39 caves.

Magmatic and other clastic rocks are impervious. Water percolates and accumulates only through the near-surface shallow weathered zone that also represents the zone of their fissure porosity. This group is comprised of Lower Sarmatian, Cretaceous, Lower Triassic, Permian – Triassic and Carboniferous – Permian rocks. Their lithological types are sandstones, siltstones, shales, marls, conglomerates, limestones, dolomites and different schists.

Groundwater of researched area belongs to the CaMg-HCO_3 hydrochemical type (BRKIĆ *et al.*, 2002), which is usual for carbonate aquifers.

Žumberak and Samoborsko gorje represent a transitional region between the north western Dinarides and Southern Alps. PAMIĆ & TOMLJENOVIĆ (1998) considered this as a north western boundary of the Internal Dinarides through the Zagorje – Midtransdanubian shear zone (ZMTZ) that was thrust on the External Dinarides. The same thrust is in MIOČ & PAMIĆ (2002) placed in the Sava nappe which was, as a part of the ZMTZ, thrust onto the northern margin of the Adriatic – Dinaridic or Mesozoic carbonate platform, e.g. External Dinarides. The ZMTZ shows Alpine and Dinaridic characteristics, including elements of both the External and Internal Dinarides.

METHODOLOGY

The first method applied was the hydrogeological field research into springs over the whole area of the Park (342.52 km^2) according to the Croatian Basic Maps scale 1:25000. It included determination of the springs from the study by BRKIĆ *et al.* (2002), identification of new springs, of a spring's lithostratigraphic unit, type and number of springs, discharge, capture and inclusion in the water supply.

Geographic coordinates and altitudes of springs were recorded using a Garmin Summit GPS device.

A unique five-digit spring identification number (ID) was developed to assure data accuracy and was assigned to each spring during the fieldwork. The first digit was labeled 1 – 8 according to the respective topographic Croatian Basic Maps scale 1:25000 (eight maps cover the area of research, Fig. 2).

The second digit was the number 1 denoting the occurrence of a spring (number 2 indicated a ponor). The last three digits were the number of researched spring on the particular topographic map and can range from 001 to 999. For the example the Slapnica spring had ID 21002 where the first digit 2 meant the spring was located on a topographic map 2 – sheet Sošice, the second digit 1 meant it was a spring, and the last three digits were 002 (Fig. 2) as it was the second researched spring on that map.

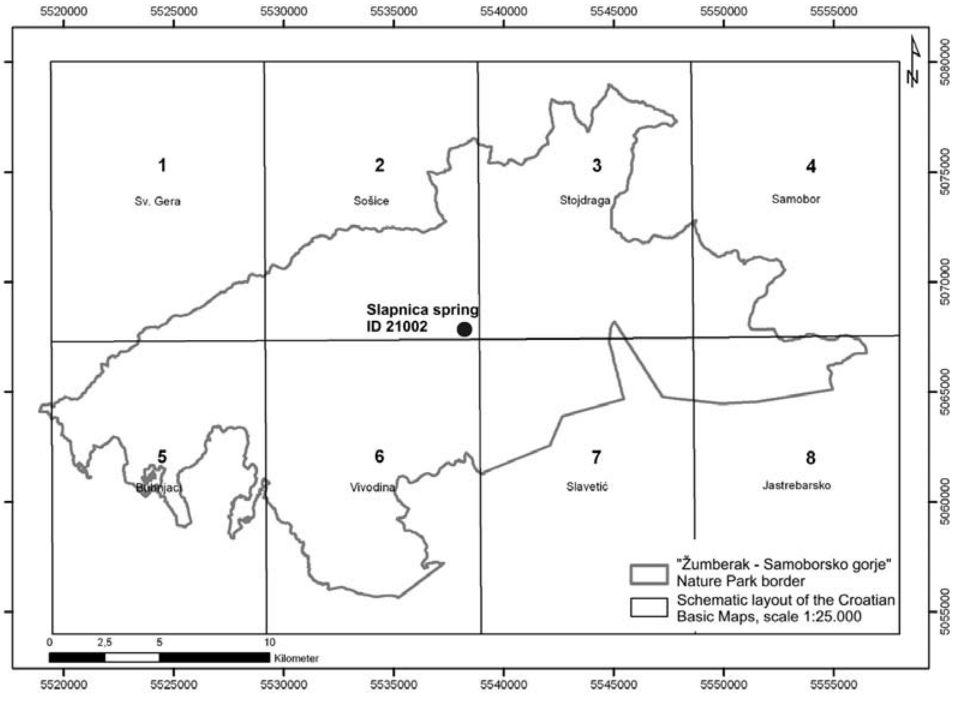
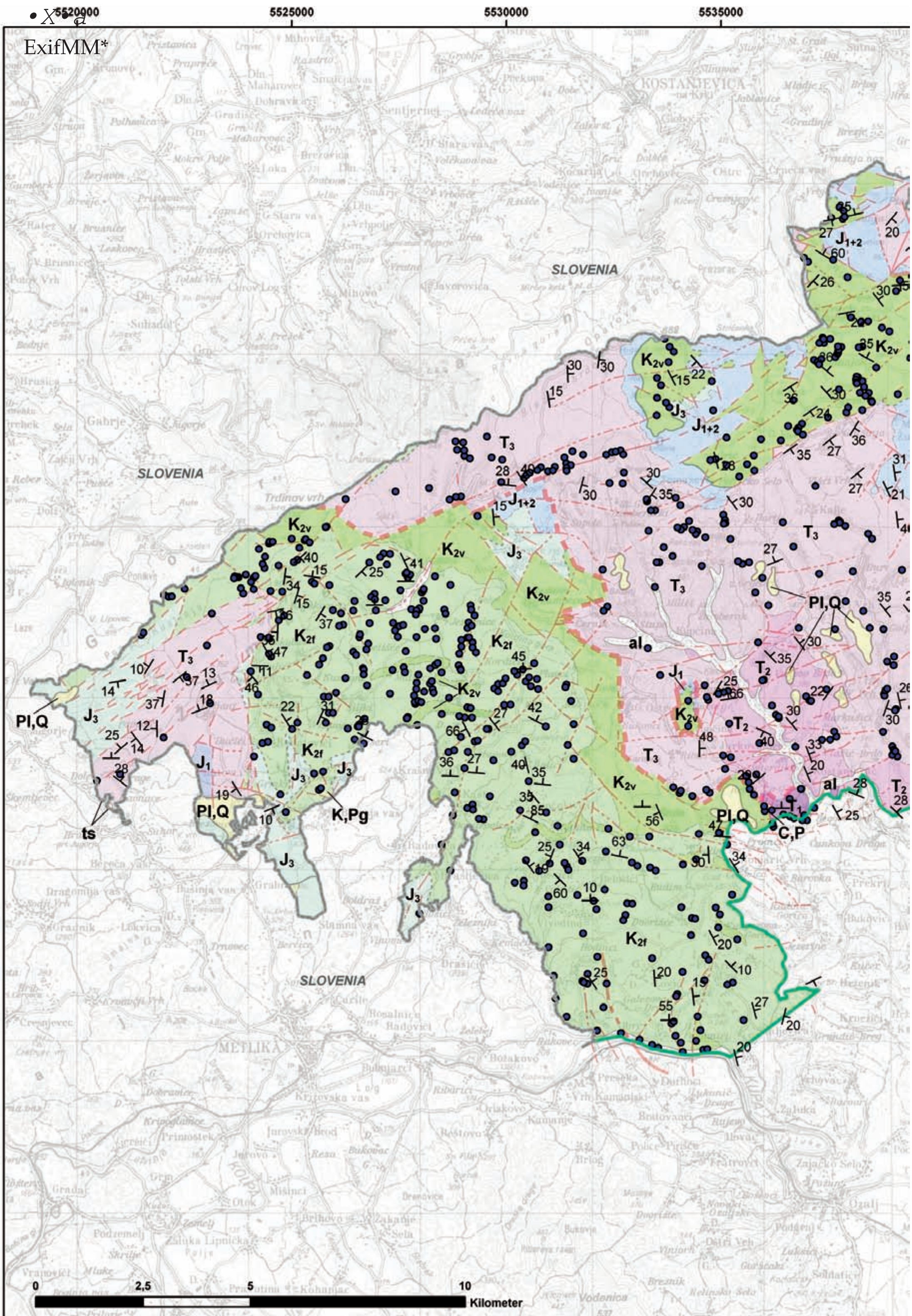


Fig. 2. The coverage of the researched area by the topographic Basic Croatian Maps, scale 1:25.000, their names and numbers, and the location of the example Slapnica spring (ID 21002).

The values of discharge, water temperature, pH, electrolytic conductivity (EC value), total dissolved solids (TDS) and oxygen concentration were measured in situ (VUJNOVIĆ, 2010a).

Discharge was measured by volumetric method at small springs, and by Dostmann electronic Gmbh model P – 670 current meter with MiniWater probe at larger springs. All springs were labeled as permanent, intermittent or unknown. Springs were assigned »permanent« if the groundwater flowed out during the extremely dry summer and autumn of the year 2007, if larvae were found that need several years of water for their life and development (e.g. Dragonfly – *Cordulegaster* sp.), if users knew that spring never dries out, and if the spring was recorded as a permanent in the former database of the Park. Springs were assigned »intermittent« if they were dried out at the moment of mapping but with visible flowing marks. »Unknown« was assigned to springs if it was impossible to recognize »permanent« or »intermittent« discharge.

Fig. 3. Springs on the lithostratigraphic map of the studied area. The map was made after the Basic Geological Maps, scale 1:100.000 (BUKOVAC *et al.*, 1983; PLENIČAR *et al.*, 1975; ŠIKIĆ *et al.*, 1977). ⇒



5520000
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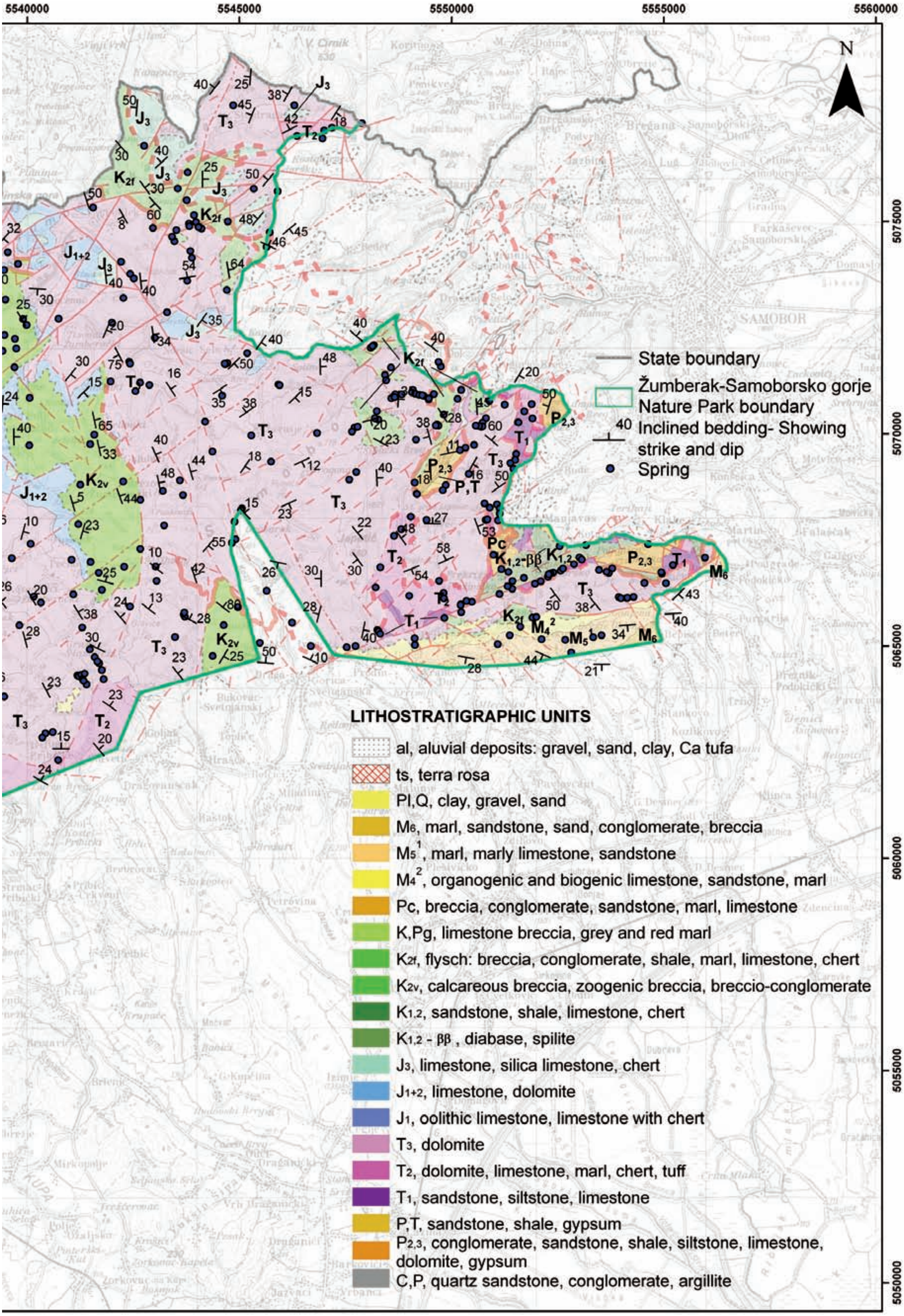
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SAMOBOR
State boundary
Žumberak-Samoborsko gorje Nature Park boundary
Inclined bedding- Showing strike and dip
Spring
LITHOSTRATIGRAPHIC UNITS
al, aluvial deposits: gravel, sand, clay, Ca tufa
ts, terra rosa
Pl,Q, clay, gravel, sand
M6, marl, sandstone, sand, conglomerate, breccia
M5 1, marl, marly limestone, sandstone
M4 2, organogenic and biogenic limestone, sandstone, marl
Pc, breccia, conglomerate, sandstone, marl, limestone
K,Pg, limestone breccia, grey and red marl
K2f, flysch: breccia, conglomerate, shale, marl, limestone, chert
K2v, calcareous breccia, zoogenic breccia, breccio-conglomerate
K1,2, sandstone, shale, limestone, chert
K1,2 - ββ , diabase, spilite
J3, limestone, silica limestone, chert
J1+2, limestone, dolomite
J1, oolithic limestone, limestone with chert
T3, dolomite
T2, dolomite, limestone, marl, chert, tuff
T1, sandstone, siltstone, limestone
P,T, sandstone, shale, gypsum
P2,3, conglomerate, sandstone, shale, siltstone, limestone, dolomite, gypsum
C,P, quartz sandstone, conglomerate, argillite

Water temperature and pH were measured by the Combo pH/EC/TDS/Temperature Tester of the Hanna Instruments, model HI 98129. The instrument was calibrated by applying standard buffer solutions of pH 7.01 and 10.01 every time before fieldwork.

EC values were measured by the waterproof EC Meter of Martini instruments, model C65, calibrated by applying standard buffer solutions of 1413 μS/cm before each fieldwork trip.

TDS values were measured by pocket TDS meter of Lovibond, Tintometer Gmbh, model Checkit micro WP TDS LR. The instrument was calibrated by applying standard buffer solutions of 998 ppm before each fieldwork trip.

Oxygen concentration was measured by oxymeter of Lovibond, Tintometer Gmbh, model SensoDirect Oxi 200.

All data collected were entered into the GIS database created for this research, with ArcEditor version 9.2 programme package (ESRI, 2006) in order to establish spatial relations with other data from Žumberak – Samoborsko gorje Nature Park. Data management and analysis included basic descriptive statistics such as percentages (%) and mean (PECK *et al.*, 2009).

RESULTS AND DISSCUSION

Altogether 847 springs were registered in the Žumberak – Samoborsko gorje Nature Park. Unique ID, geographic coordinates, altitude, lithostratigraphic unit, type and number of spring, discharge, capture, inclusion in the water supply, in situ measured discharge and basic physicochemical parameters were assigned to every inventoried spring. The majority of springs were measured only once, during different parts of the year and with hydrological conditions.

Distribution of springs by the lithostratigraphic units and altitude is analyzed and presented as the permanent characteristics of all recorded springs. It could indicate aquifer settings.

Spring's discharge distribution and physicochemical parameters (temperature, pH, electrolytic conductivity, total dissolved solids and oxygen concentration) can be presented only as possible indicators.

Springs at the lithostratigraphic units

Rocks are presented primarily after the Basic Geological Maps, scale 1:100.000, and accompanying explanatory notes for the sheets Novo Mesto (PLENIČAR *et al.*, 1975; PLENIČAR & PREMRU, 1977), Zagreb (ŠIKIĆ *et al.*, 1977; ŠIKIĆ *et al.*, 1979) and Črnomelj (BUKOVAC *et al.*, 1983; BUKOVAC *et al.*, 1984): 21 lithostratigraphic units of the researched area range from Carboniferous – Permian (Paleozoic) to Quaternary. Lithostratigraphic descriptions can be read directly from the lithostratigraphic map in Fig. 3.

The distribution of 847 registered springs by 21 lithostratigraphic units (Tab. 1) indicates the regional aquifer conditions (VUJNOVIĆ, 2010a, b).

The most springs (309) were recorded in the unit of Upper Cretaceous flysch deposits although it occupies only 22% of the researched area (Tab. 1). The reason for

Tab. 1. The list of lithostratigraphic units, their surface area and number of recorded springs.

Lithostratigraphic unit		Area		Spring	
		(km^2)	(%)	(number)	(%)
1.	Q (al)	3.46	1.01	16	1.89
2.	Q (ts)	0.02	0.01	0	0.00
3.	Pl,Q	2.77	0.81	0	0.00
4.	M_6	0.44	0.13	0	0.00
5.	M_5^1	3.64	1.06	7	0.83
6.	M_4^2	1.93	0.56	3	0.35
7.	Pc	0.69	0.20	2	0.24
8.	K,Pg	0.00	0.00	0	0.00
9.	K_{2f} (flysch)	75.84	22.14	309	36.48
10.	K_{2v} (carbonates)	44.70	13.05	135	15.94
11.	$K_{1,2}$	2.38	0.69	12	1.42
12.	$K_{1,2}$-β-β	13.96	4.08	0	0.00
13.	J_3	15.75	4.60	7	0.83
14.	J_{1+2}	0.59	0.17	1	0.12
15.	J_1	0.05	0.02	0	0.00
16.	T_3	155.97	45.54	287	33.88
17.	T_2	15.73	4.59	37	4.37
18.	T_1	2.50	0.73	27	3.19
19.	P,T	0.31	0.09	2	0.24
20.	$P_{2,3}$	1.76	0.51	2	0.24
21.	C,P	0.03	0.01	0	0.00

such abundance is a characteristic interchange in clastic or clastic and carbonate layers, i.e. the impermeable clastic and permeable karstified carbonate strata. Springs drain thin carbonate layers locally and discharges are mostly small, a large part of them drying out during the summer months. Most of their waters get turbid with precipitation due to weathering and leaching of clastic sedimentary rocks.

By the abundance they are followed by 287 springs from Upper Triassic dolomites. That is in accordance with the lithostratigraphic unit area that covers 46% of the researched terrain (Tab. 1). These springs are generally permanent, which means they have significant background from the aquifer. Their waters do not get turbid with precipitation because they flow through fractured dolomites without clastic deposits capable of weathering and leaching. Large T_3 springs are generally captured for water supply – by companies Komunalno Jastrebarsko, Vodoopskrba i odvodnja Samobor, Komunalno Žumberak. The Kupčina spring (100 l/s on 14.2.2008.) and the Slapnica spring (90 l/s on 20.6.2007.) were the largest registered, they are formed within this lithostratigraphic unit and not captured.

Upper Cretaceous carbonate deposits cover 13% of the research terrain and follow with 135 recorded springs. Their abundance is in proportion to the coverage area of that lithostratigraphic unit.

Altitude

The distribution of the Upper Triassic and Upper Cretaceous springs by altitude could indicate the recharge and discharge zones of the aquifers. Distribution of the rest of springs was not done because of their inappropriate number for statistical analysis. Upper Triassic and Upper Cretaceous rocks have the highest prevalence in the Park and could be found from the lowest altitudes below 200 m a.s.l. to the highest parts above 1000 m a.s.l.

Most of the Upper Triassic springs (36%) flow out at the altitude from 301 to 400 m a.s.l., 23% springs from 401 to 500 m a.s.l., and 16% from 201 to 300 m a.s.l. (Fig. 4).

At altitudes lower than 200 m a.s.l. and higher than 501 m a.s.l. the number of springs significantly decreases. Such a distribution was in accordance with expectations since it was assumed that the groundwater of dolomitic aquifers recharges at higher altitudes, and discharges at lower altitudes, at erosional bases. The aquifer has a significant horizontal and vertical prevalence (Fig. 3) that allows such a flow and discharge.

The distribution of the Upper Cretaceous springs is quite different (Fig. 4) and shows that most of the springs (33%) can be found at the altitude from 601 to 700 m a.s.l.. The share of the springs at altitudes from 701 do 800 m a.s.l. is 14%, and from 501 do 600 m a.s.l. is 13%. Other classes of altitudes are equally poorly represented. Such a distribution of springs indicates the dominant draining of local small catchments in the mostly flysch heterogeneous aquifer.

Discharge

The distribution of springs by discharge was made only as an indicator of potential volume of discharge (VUJNOVIĆ, 2010a, b).

The majority of the springs (648) are permanent. Intermittent discharge was assigned to 112 springs, and an unknown discharge to 87 springs. The number of in-

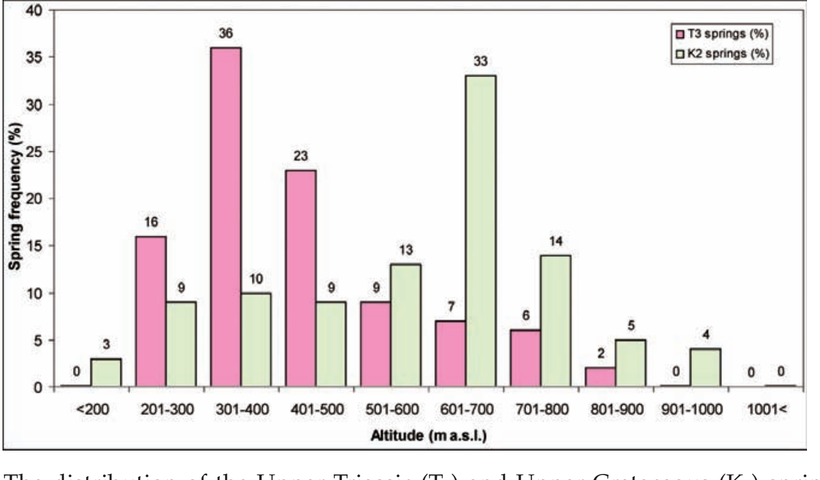

Fig. 4. The distribution of the Upper Triassic (T_3) and Upper Cretaceous (K_2) springs by altitude.

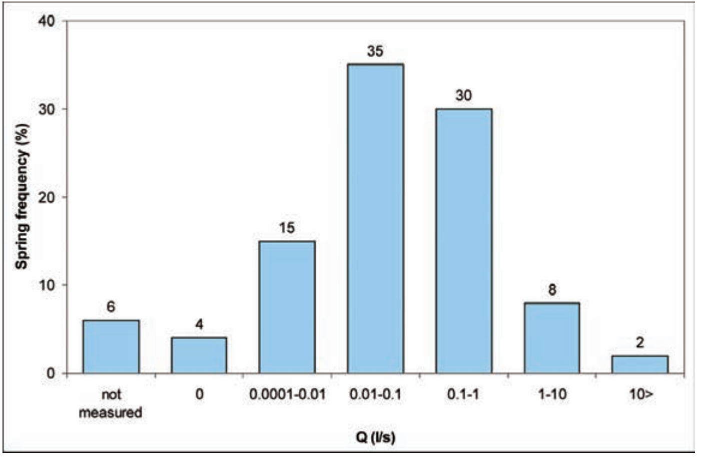

Fig. 5. The distribution of springs by discharge.

termittent springs is probably several times higher than recorded due to the geological settings and structure of the studied terrain.

According to measurements from the year 2007 and the part of 2008, it is evident that the largest number of springs (35%) is within the class of discharge from 0.01 to 0.1 l/s (Fig. 5). Such springs were commonly used for local water supply in the past, and still are today. They are often simply captured for domestic and livestock water supply.

Larger springs in the class of discharge from 0.1 to 1.0 l/s have an abundance of 30% and are often used for water supply. They are followed by springs (15%) that had discharge of 0.0001 – 0.01 l/s at the moment of measurement. Large springs from discharge classes 1 – 10 l/s had a share of 8 %. The share of 6 % was registered for springs where it was not possible to measure discharge due to different reasons (e.g. capture closing). There were 4% of intermittent springs that had dried out by the moment of recording. The minimum share of 2% was reported for springs where the measured discharges were greater than 10 l/s which is consistent with a carbonate, very tectonically disturbed shallow karst aquifer. The sum of all discharges larger than 0.1 l/s gives a share of 40%, which indicates significant groundwater reserves in the aquifers of the Žumberak – Samoborsko gorje Nature Park.

Measured physicochemical parameters

The basic measured physicochemical parameters are presented only as an indicator of possible aquifer hydrochemistry. The parameters were divided after springs lithostratigraphic units, as different rocks give different hydrochemistry (APPELO & POSTMA, 1996; HEM, 1985). The statistics of parameters is shown only for the lithostratigraphic groups of springs where the total number of springs was larger than ten (Tab. 2). As the majority of springs were recorded and measured only once during different season of the year it was necessary to divide them in two seasonal groups. The first was measured during summer base flow conditions, and the second one during winter, spring and autumn time (WSA). The mean annual values

Tab. 2. The list of lithostratigraphic units (with more than 10 total registered springs) by number of springs recorded during winter, spring and autumn – N_{WSA}, during summer – N_S, total number of recorded springs – N_T, mean discharge – Q (l/s), mean temperature – T (°C), mean pH, mean electrolytic conductivity – EC (µS/cm), mean total dissolved solids – TDS (mg/l) and mean oxygen concentration – O_2 (mg/l).

Lithostratigraphic unit	N_{WSA} N_S N_T	Q (l/s)	T (°C)	pH	EC (µS/cm)	TDS (mg/l)	O_2 (mg/l)
Q (al)	16	1.81	12.76	7.59	537	363	4.50
K_{2f} (flysch)	142	0.41	10.75	7.84	399	285	4.39
	167	0.15	11.68	7.76	412	302	4.85
	309	0.26	11.23	7.80	408	293	4.54
K_{2v} (carbonates)	60	0.16	11.50	7.56	334	238	4.18
	75	0.62	12.34	7.54	390	274	4.80
	135	0.51	11.96	7.55	383	275	4.27
$K_{1.2}$	12	0.27	10.45	7.75	490	348	4.43
T_3	187	2.34	10.86	7.55	446	313	4.71
	100	0.72	13.97	7.71	437	303	4.67
	287	1.78	11.73	7.60	438	310	4.71
T_2	25	0.78	10.32	7.65	504	330	4.85
	12	0.08	14.62	8.11	527	350	4.43
	37	0.55	11.35	7.76	513	335	4.73
T_1	19	0.61	11.63	7.83	432	301	4.76
	8	0.10	11.70	7.63	603	420	4.41
	27	0.45	11.64	7.79	463	325	4.70

were given for springs in five lithostratigraphic groups with a similar number of measurements during whole season.

The water **temperature** at the spring indicates its recharge area and it should be in accordance with its annual air temperature. The groundwater temperature in karst varies from 4.9 °C to 17.8 °C (BONACCI, 1987). The lowest mean annual water temperatures of 11.23 °C were found in K_{2f}, springs and the highest of 11.96 °C in K_{2v} springs. Both temperatures were above mean annual air temperature, so shallow groundwater circulation could be indicated.

Negative logarithm of the hydrogen ion concentrations (**pH** value) – The hydrogen – ion activity in an aqueous solution is controlled by interrelated chemical reactions that produce or consume hydrogen ions (HEM, 1985). The pH value of a natural water is a useful indicator of the status of equilibrium reactions. One of the most important reactions in establishing H^+ ions in natural – water systems is dissolved carbon dioxide in water. Atmospheric partial pressure of CO_2 is constant ($pCO_2 = 10^{-3.5}$ atm) while in the soil pCO_2 varies depending on the depth and seasonal changes (APPELO & POSTMA, 1996). The main source of CO_2 in soil is plant respiration or the oxidation of organic substances, and the highest soil pCO_2 values are in summer because of the intensive biomass activity. The groundwater pCO_2 values are lowest and pH values are highest in the summer because precipitation is very rare and there is no water that could bring CO_2 by infiltration through the surface. The pH of waters in limestone and dolomite terrains usually falls between 6.5 and 8.9 (FORD & WILLIAMS, 2007). The spring waters of the studied area were weakly alkaline according to the measured average pH values of 7.55–7.80. Lower WSA pH values were found in the groundwater of T_2 and T_3 springs, than during the summer base flow conditions (Tab. 2), which is common, as mentioned before. The groundwater of T_1, K_{2f} and K_{2v} springs had lower pH values during summer, with increase during WSA (Tab. 2). That could again indicate shallow groundwater circulation, as such pH values are characteristic of soils.

Electrolytic conductivity (**EC**) and total dissolved solids (**TDS**) are correlated – pure water has low EC value and it increases with the increase of TDS (HEM, 1985). The increase of temperature causes an increase of EC values also. Groundwater from dolomites usually has lower EC values than that from limestones because limestones are more soluble. The time needed to reach 95% saturation for dolomites is 100 times longer than that for limestones under similar conditions (APPELO & POSTMA, 1996). The lowest mean annual EC of 383 µs/cm was found in K_{2v} springs and the highest mean annual EC of 513 µs/cm in T_2 springs. Generally, the highest values were measured during summer base flow conditions (Tab. 2). In the spring or winter months the recharge is greater, it causes greater dilution and lower EC values than in the summer period. EC values could not be assigned to limestones or dolomites because they were measured only once and the terrain has complex thrust – fold – imbricate structure.

Dissolved oxygen concentration (**O_2**) has a significant effect upon groundwater quality by regulating the valence state of trace metals and by constraining the bacterial metabolism of dissolved organic species. Oxygen solubility is directly related to atmospheric pressure and inversely related to water temperature and salinity. The lowest mean annual O_2 concentration of 4.27 mg/l was found K_{2v} springs and the highest of 4.73 mg/l in T_2 springs (Tab. 2).

CONCLUSIONS

This research intended to determine the wealth of groundwater of the Samoborsko gorje and Žumberak area by using numerous collected and measured hydrogeological parameters. For this purpose, fundamental hydrogeological research was carried out in the period 10.4.2007.–15.3.2008. That was the first hydrogeological study that approached this intriguing karst area as a whole. The conclusions after the research are as follows:

- There were 847 registered springs altogether, of which 503 are newly registered.
- Spring discharges and basic physicochemical parameters in situ were measured at least once.
- All collected and measured data were entered in a GIS database created for this purpose.
- Most of the springs (309) were formed in Upper Cretaceous flysch deposits. They had the lowest all seasonal mean discharges of 0.26 l/s, indicating small, local recharge areas.

• They were followed by the springs from Upper Triassic dolomites (287) with mean annual discharge of 1.78 l/s. Upper Triassic dolomites constitute the dominant aquifer of the researched area.

• The largest mean discharge of 1.81 l/s was found in springs from the alluvial Quaternary deposits, measured only in summer conditions. This is the result of their erosional basis position (streams at low distal altitudes parts of the Park) where groundwater tends to drain.

• The Kupčina (100 l/s on 14.2.2008.) and Slapnica (90 l/s on 20.6.2007.) springs were the largest registered springs. They are within Upper Triassic lithostratigraphic unit and are not captured.

• Most registered springs had permanent discharge.

• Upper Triassic springs recharged at higher altitudes than Upper Cretaceous springs.

• The dominant springs (35%) had 0.01–0.1 l/s discharge.

• They were followed by the springs (30%) of 0.1–1.0 l/s discharge.

• Mean annual temperature ranged 11.23–11.96 °C.

• The spring waters of the studied area were weakly alkaline, mean annual pH values varyring from 7.55 to 7.80.

• Mean annual EC values ranged 383–513 μS/cm.

• The highest EC values were measured during summer base flow conditions.

• The mean annual O_2 concentrations ranged 4.27–4.73 mg/l.

• Measured values could not be assigned to certain rock lithotypes or units because they were measured once in the majority of springs, and the terrain has a complex thrust – fold – imbricate structure.

The results of this research should represent a solid base for all future hydrogeological studies. The next step would be to choose »representative« springs that should be measured and monitored on a regular base, for a minimal duration of one hydrological year. This should improve understanding about the functioning of this open carbonate hydrogeological system and enable the assessment of its natural vulnerability.

This research indicates the significant groundwater reserves in the Žumberak and Samoborsko gorje area, which could be a vital potable water source for future generations.

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