Regeneration process of the karst water springs in Transdanubian Mountains, Hungary

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Abstract

Since the 1940s and 50s, there have been several researches dealing with karst water springs and the mapping of the continuous karst water level of the Transdanubian Mountains. The karst water level sank because of the intense bauxite and coal mining between the 1950s and 1980s and it started to increase after the decrease of mining activity. However, only a few authors investigated and modelled the water level changes and the rejuvenation of karst springs in the karst reservoir. Our paper is about the mineral contents and geomorphic properties of karst water springs near a chosen reservoir and our aim was to get some information about the regeneration process of the karst water reservoir. The geomorphic properties of karst water springs were mapped, using detailed field survey (DGPS) and geomorphic mapping. The mineral contents of spring waters were analysed to prove their origin. GIS results show that the karst water level in the karst reservoir reached 180–190 m a.s.l.

Keywords:, karst water spring, karst water level, mineral contents, geomorphological mapping, Transdanubian Mountains

Introduction

The term of karst water stems from Grund, A. (1903) who applied it to karst water accumulated in the holes of dolomite and limestone mountains (Schréter,

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Z. 1940). Höfer, H. (1912) classifies the subsurface waters of the karst areas as the subset of rock-moving waters (*Felswasser*), cave waters (*Höhlenwasser*) called Triassic water by the Hungarian mining engineer Szádeczky-Kardoss, E. (1941) who used this term, too.

According to Kállai, G. (1927), the term mentioned above can be thanked to Jex, S. who was a former mining director in Tatabánya and who first applied the term Triassic water to vadose water streaming in the Triassic limestone bed. In the respect of karst water research dealing with karst phenomenon, the work of Cvijič, J. (1893) is also worth mentioning.

At the beginning of the 1940s heated discussion evolved among the Hungarian and the foreign hydrologists about the continuous interconnected karst water level of karst water reservoir of Transdanubian Mountains. The theory of Katzer, F. (1909) was accepted by some researchers (Höfer, H. 1912; Keilhack, K. 1912; Lehmann, O. 1932) who believed that continuous karst water level can be observed very rarely and their regular distribution of karst water is more frequent (Schréter, Z. 1940). In contrast, others adopted the continuous interconnected karst water level theory by Grund, A. (1903) to the area of mountains (Schréter Z. 1940).

Grund (1903) suggested a continuous interconnected karst water level in the limestone of the karst region in a way which able the accumulated, mustered waters to run on and communicate with each other in every direction in the fracture network of limestone mountain hereby the continuous subsurface water level evolves similarly to the phreatic water. According to the opinion of Szádeczky-Kardoss, E. (1948), the theory of Grund can be accepted in case of deeper karst (for example Transdanubian Mountains) while in case of shallower karst, the theory of Katzer can be applied.

Szádeczky-Kardoss started his research to create the first Hungarian karst water map on the South part of the Transdanubian Mountains in the second half of the 1930s. He determined that the karst water level stands out well at 109–146 m a.s.l. in the area of Keszthely Mountains, below that height, water abundance and above that height, a shortage of water can be experienced. The theory of the continuous interconnected karst water reservoir was accepted around the 1940s and 1950s (Szádeczky-Kardoss, E. 1941, 1948) which is due to the hydrogeological researches related to the bauxite and coal mining below the karst water level.

At the same time the karst water level maps were illustrated with izohypses were born concerning the area of the surface karst water level and its wider environment (Szádeczky-Kardoss, E. 1941, 1948). Alföldi, L. (2007) put the modern knowledge of the geological and hydrogeological background of the karst water reservoir into a unified framework.

After World War II the increased industrialisation demanded more and more raw materials, but that demand couldn't be satisfied with surface and near surface mines because of their depletion, which affected deep mining endangering the subsurface and karst water inrush. It went hand in hand with the active and later the passive anhydrous of the mine tunnels. Later its amount – Csepregi, A. (2007) calculated (estimated) an amount of 10 billion m^3 exploited karst water between 1951 and 1990 – exceeded the average amount of 500 m^3/s infiltration being necessary for the natural regeneration of the karst water reservoir (Csepregi, A. 2007). The water removals on spots or in smaller areas had an impact on the whole area because of the connected water level in the Széki Reservoir (3 km NW from Ajka). Apart from some exceptions, almost all karst springs of the Transdanubian Mountains have dried up or their yields have decreased significantly (*Figure 1*).

Since the 1990s, the karst water level has begun to rise (*Figure 2*) as a result of mine closures and the dewatering works, however, at the beginning, very different and often exaggerated calculations related to the entire period of the regeneration of the reservoir emerged. According to the latest model calculations, the almost total refill of the reservoir can be expected by mid- or second half of the 2020s (Csepregi, A. 2007).

On 4th October 2010, while examining the possibilities of the dewatering of the reservoir of MAL Zrt. (Hungarian Aluminium Corporation), following its tailings

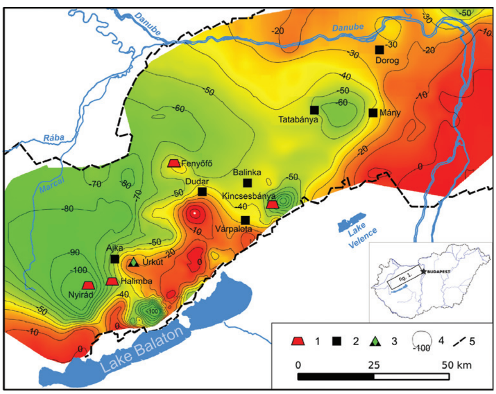

Fig. 1. Karst water level in 1990 comparing to the original karst reservoir conditions (based on Csepregi, A. 2007). – 1 = bauxite mine; 2 = coal mine; 3 = manganese mine; 4 = relative karst water level; 5 = border of the karst water reservoir

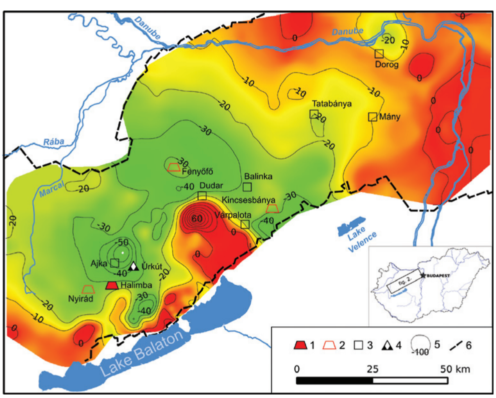

Fig. 2. Karst water level in 2006 comparing to the original karst reservoir conditions (based on Csepregi, A. 2007). – 1 = bauxite mine; 2 = closed bauxite mine; 3 = closed coal mine; 4 = closed manganese mine; 5 = relative karst water level; 6 = border of the karst water reservoir

rupture, sludge disaster (Schweitzer, F. 2010), we noticed intensive spring works on the surface around the Széki Reservoir (Schweitzer, F. and Viczián, I. 2011). Investigating the causes of the sludge disaster, the engineer report (Mecsi, J. 2012; Turi, D. *et al.* 2013) highlighted the role of ground water in the disaster which can be closely related to the recovery of the resources tapping the increasingly restored karst water.

The aim of our study is to identify the sources, the origin of spring water found near the Széki Reservoir in 2010 and their relationship with the karst water reservoir. Besides, as a subgoal, we will define the source areas and the sketching of their geomorphological situation.

Site description

Our investigation area is situated in Pápai-Bakonyalja physical geographical microregion, in the valley of Csigere Creek (*Figure 3*). From the geomorphic point of view, it covers the lower, Southwestern part of the hillslope of the Bakony

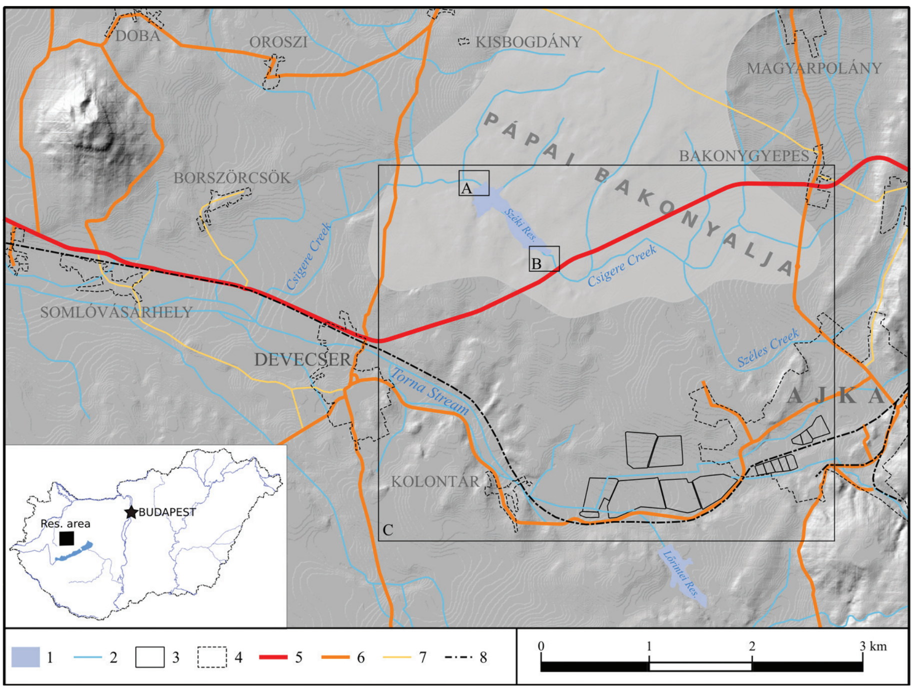

Fig. 3. Sketch of the investigated area. – 1 = water reservoir; 2 = water course; 3 = sludge reservoir; 4 = residential area; 5 = primary road; 6 = secondary road; 7 = tertiary road; 8 = railroad; A, B, C = detailed sketches (See *Figs 4–7)*

Mountains (Dövényi, Z. ed. 2010). The higher parts of the Bakony Mountains in the East and the lower Quaternary alluvial fan system in the West are connected by the Csigere Creek Valley. Detailed field mapping was done West and Southwest from the Széki Reservoir created by the dam construction at the Csigere Creek.

The area is built up from up to 1,000 m thick Cretaceous calcareous sediments covered by 250 m thick clay, conglomerate, marl and limestone layers of Eocene transgression (Bohn, P. 1983). The bedrock in the areas North and Northwest from the reservoir contains the Eocene limestone layers. Thick layers of Oligocene and Miocene conglomerates are superimposed on limestone, they cover the surface in the Western part of the reservoir.

Methods

Detailed geomorphic mapping based on 1:10,000 scale topographic and orthophoto maps published in 2005 was done to clear the position and the geomorphic properties of karst springs and their surroundings. The 2.5 m vertical resolution of the topographical map and the vegetation cover on the orthophoto map impeded the identification of the exact altitudinal and horizontal positions of karst springs. Hence, karst springs and their surroundings were surveyed by Topcon FC-250 differential GPS (DGPS). The survey was hindered by the dense vegetation, accordingly, the accuracy of the measurements was maximum 50 cm (horizontal) and 20 cm (vertical). The unequivocally identified karst spring outlets were measured more precisely, with subcentimeter accuracy. The surveyed data were processed with Grass GIS 6.4.2., Qgis 1.6.0. and Inkscape 0.48 was used to draw the detailed geomorphic sketch.

The height values of karst spring outlets were compared to the "original" (before the 1950s) karst water level of the izohypse maps (Jaskó, S. 1959; Csepregi, A. 2007) to identify the karstic origin of the springs. The izohypses were digitised using v.digit module of Grass GIS 6.4.2. and they were interpolated with v.surf.rst module using spline interpolation (Mitasova, H. *et al.* 2005) and 100 m horizontal resolution was applied. The DEM of the "original" karst water level was smoothed using 33×33 convolution matrix and an averaging technique. r.resap was used to increase the horizontal resolution of the DEM of karst water level to 10 m. The DEM of the „original" karst water level was compared to the DEM of the land surface using r.mapcalculator. The map clearly shows the place where the „original" karst water level crosses the surface and it also demonstrates if the areas are under karst water pressure or not. The mineral content of water samples taken from springs were analysed to clear their origin. Results were compared to the mineral contents of karst waters published by former authors. 1.5 litre spring waters were sampled from springs 3 times during the observation period (*Figures* 4 and 5).

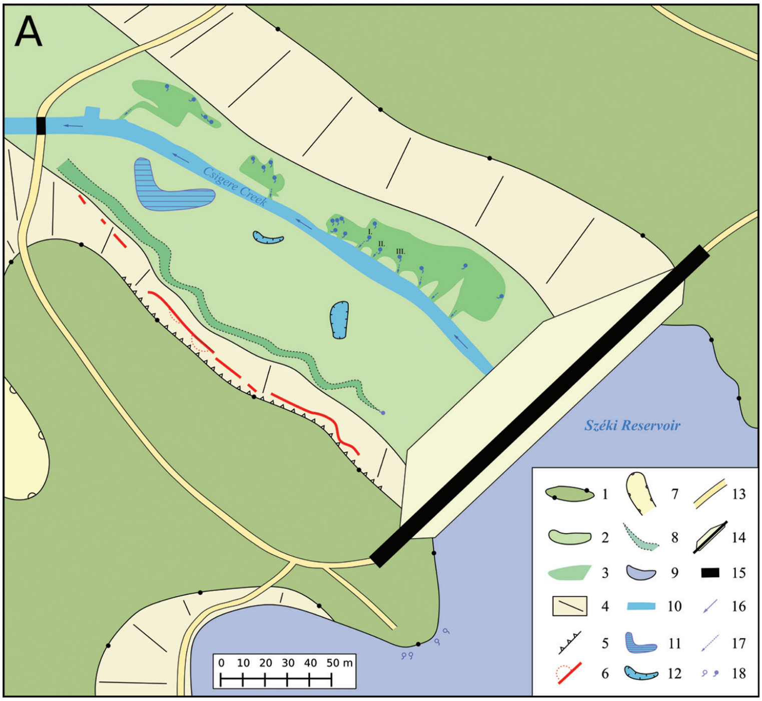

Fig. 4. Geomorphic sketch of the karst spring area, NW from the Széki Reservoir (area 'A' inside *Fig. 3*). – 1 = hillslope; 2 = flood plain; 3 = waterlogged surface pach; 4 = slope; 5 = high bluff; 6 = travertine with overhanging slope; 7 = dry valley; 8 = ephemeral channel; 9 = water reservoir; 10 = channel; 11 = oxbow lake; 12 = artificial lake; 13 = unpaved road; 14 = dam; 15 = bridge; 16 = waterflow direction (in the channel); 17 = water flow direction (on waterlogged area); 18 = karst springs

As a result of the environmental analyses, mostly very low concentrations of materials were established. The results of the measurements are usually expressed in the unit of "gram per litre," (g/l). Water analyses can be done by several methods. The most common and oldest type of measurement is titration. Instrumental methods are becoming more and more popular. Our measurements were made according to the Hungarian Standards (MSz).

Titration depends on using a well-defined chemical reaction to measure the amount of a standard solution needed to react with a defined amount of the sample. A known volume of sample is placed into a beaker and the standard reagent is dispensed from a burette to the sample (thus the volume of standard reagent can be measured). The "endpoint" of the reaction is determined by observing the colour change using an indicator or by observing the physical-chemical change in the solution using an instrument. Knowing the amount of the standard reagent, the amount of the analysis can be calculated in the sample.

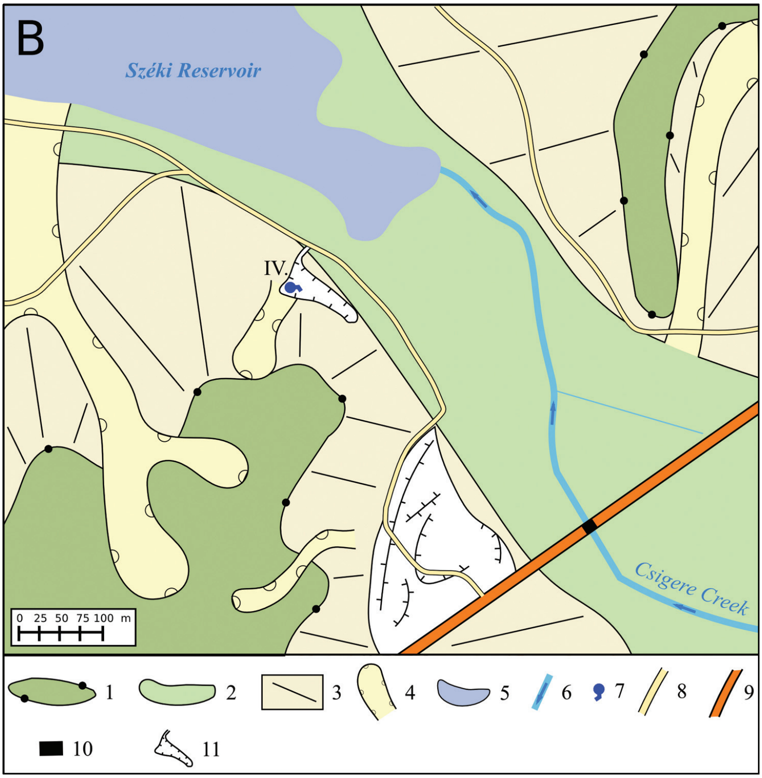

Fig. 5. Geomorphic sketch of the karst spring area, W from the Széki Reservoir (area 'B' inside *Fig. 3*). 1 = hillslope; 2 = flood plain; 3 = slope; 4 = dry valley; 5 = water reservoir; 6 = water course; 7 = spring; 8 = unpaved road; 9 = primary road; 10 = bridge; 11 = quarry

Alkalinity is a measure of water's ability to neutralize acids. Bicarbonate, carbonate and hydroxide ions are the most common causes of alkalinity. The alkalinity of water is determined by end-point titration with a strong acid solution (HCl). Titration to pH 8.3 (decolourisation of phenolphthalein indicator) will indicate the complete neutralization of OH^- and half of CO_3^{2-} while titration to pH 4.5 (sharp change from yellow to orange of methyl orange indicator) will indicate total alkalinity {MSz 448-11 and ISO 9963-1}.

Hardness is determined by the concentration of cations, Ca^{2+} and Mg^{2+} are common cations in hard water. The water runs through the rocks containing minerals such as gypsum ($CaSO_4 \bullet 2H_2O$), calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$).

Temporary or bicarbonate hardness is caused by the presence of dissolved bicarbonates of calcium, magnesium and other heavy metals. It's determined by end point titration with a strong acid solution (HCl) using methyl orange as indicator {MSZ 448-21}. Ca^{2+} and Mg^{2+} can be combined with chlorides and sulphates resulting in *permanent hardness of water* which can't be removed by boiling. The permanent hardness of water is determined by complexometric titration using EDTA (ethylene-diamine-tetraacetic acid) at pH 10 (both Ca^{2+} and Mg^{2+} will complex with EDTA at that pH value) {MSZ 448-3 and MSZ 448-21}. Standard laboratory glasware such as burettes, volumetric flasks and beakers [Beakers (100 ml), Burette (25 ml), Graduated cylinder or pipette (100 ml), Whatman filters (only for suspended materials)] were used during the analysis.

Results

The geomorphic position of karst springs

The construction of the ~10 m high dam of Széki Reservoir at the Csigere Creek was finished in 1978 and it also involved the channel regulation of the creek. The outflow water leaves the dam and flows in an artificial, 4 m wide channel towards west (*Figure 4*). The channel bisects the former, 70–90 m wide alluvial flat of Csigere Creek which cut a 7–10 m deep valley into the sediments on the hillslope of Bakony Mountains. The Western part of the planar surface of the floodplain (179–181 m a.s.l.) is dissected by two small, artificial lakes, a former meander of Csigere Creek and an ephemeral channel of a karst spring.

The alluvial plain is connected to the hillslope being a result of the lateral erosion of Csigere Creek with a steep slope. The Eocene bedrock and the superimposed travertine structure are clearly visible along a 195 m long section of the steep slope. The identification of the Eocene limestone and the young travertine junction is quite difficult, because the travertine contains a lot of reworked fossils (*Nummulites sp*.) from Eocene layers. However, their mass is lower in the travertine structure than in the Eocene bedrock. In addition, the typical overhanging slopes of travertines rimstone barriers also prove their karst water origin.

Two – 1.8 m high, 1 m deep and 1 m high, 0.5 m deep – overhanging slope hollows (*Photo 1*) were also observed close to each other in the travertine structure. All of the observations prove a former, intense period of spring activity.

The Eastern part of the floodplain is connected to the hillslope with a gentle slope. There is no travertine, only Eocene limestone is exposed along a short, 1 m long section between the slope and the floodplain. The Eastern part of the floodplain is covered by waterlogged surface patches. They occur in an area of 200 m long and 20–30 m wide along the floodplain and their areas are ~1,400 m^2, 180 m^2 and 420 m^2, respectively, extending from Southeast to Northwest. They are separated from the floodplain with a 20–50 cm high berm. 12 clearly visible karst water springs were identified on the most extensive waterlogged surface patch and 8 others on the smaller patches at 180.6 m a.s.l.

Photo 1. Typical fossil travertine structure on the steep slope of the Csigere Creek (Photo by KOVÁCS, I.P.)

The number of the identified karst water springs is lower than their real number due to their difficult-to-reach location and the dense vegetation cover. The vegetation indicates the temperature of the karst water springs (10–12 °C). Vegetation covered the waterlogged surface patches during our fieldtrips in February (*Photo 2*).

The outflow waters run in small, 0.5–1.5 deep erosional channels to the Csigere Creek, however, measuring the discharge was impossible. The rejuvenation of the karst spring activity is shown by the recent yellow and reddish, calcareous mud and the lack of travertines in the surrounding of the springs (*Photo 3*). The calcareous mud coats leaves and boughs and it forms low rimstone barriers (*Photo 4)*.

Underwater karst spring outlets were observed in the Northern part of the reservoir, South from the dam. The frozen underwater karst springs being warmer than the water of the reservoir melted and broke through the ice on the reservoir (*Photo 5*).

There is a quarry, 40 m southwest from the reservoir on Oligocene-Miocene gravels (*Figure 5*). Reed (*Poaceae australis*) patches and willows (*Salix alba*) indicates the karst water springs at the northern end of the mining claim. The spring activity is not so intense here the water leaks and fills up the mining claim. 0.5 m thick calcareous mud was deposited at the mouth of the spring, however, it's colour is lighter comparing to the mud mentioned above, probably due to the lower concentration of iron compounds.

Photo 2. Warm (12 °C) karst water of waterlogged surfaces around the springs with greenery in February 2013. (Photo by Kopecskó, Zs.)

Photo 3. Leaves covered by recent calcareous mud near the springs (Photo by Kovács, I.P.)

Photo 4. Approx. 3 cm high recent rimmstone dams near karst springs (Photo by Kovács, I.P.)

Photo 5. Underwater karst springs brake trough the ice of the water reservoir in February 2013. (Photo by Kovács, I.P.)

The results of the chemical analysis of water

The content included in the analysis of water samples mineral follows a common pattern (*Table 1* and *2*). The HCO^- from 345.5 to 394 mg/l Ca^{2+} were measured from 99.5 to 146.7, and Mg^{2+} is between mg/l 33.6 and 41.4. The Ca^{2+} and Mg^{2+} ratio is between 2.7–2.8. The hardness of the samples varied from 15.9 to 18.1, while permanent hardness is somewhere between 22 and 29.9.

Three springs of the Széki Reservoir in the Northwest part provided very similar data, while some parameters (of the springs) showed significant differences in the southwest part of Széki Reservoir. The resulting Ca^{2+} in water compared to 30–40 Mg^{2+} content of 3–4 mg/l is greater than that of the average of other sources. It affects all of the permanent hardness of which more than 7 units of other sources of water. The measured results collected and published by Szádeczky-Kardoss, E. (1940, 1941) represent highland karst water mineral content and temperature (*Table 2*).

Table 1. Measured chemical parameters of water samples

Parameter	Amount
Temperature	10–14°C
Ca^{2+}	70–110 mg/l
Mg^{2+}	30–50 mg/l
$Ca^{2+} : Mg^{2+}$	2.1–2.7
HCO^-	dominance
Temporary hardness	15–23
Permanent hardness	20–25

GIS results

According to the results of the comparison of the "original" karst water level (Csepregi, A. 2007) and the height values of the mapped karst water springs (*Figure 6*), it is proved that the recent spring activity is under the "original" karst water level. Karst springs being Northwest from the reservoir are 4.2–5.6 m below the “original” level on average, but the karst spring west from the reservoir is just 0.5–1.5 m below it. At the red mud reservoir No. 10, the values are between 7 and 6 m, furthermore, the older sludge reservoirs are 4–6 m deeper than the "original" karst water level.

Using the "original" karst water level by Jaskó, S. (1959), the results are quite different (*Figure 7*). The Northwestern karst springs are situated 3.5–5.6 m higher than the "original" karst water level, whereas the South-Western springs, reservoir No. 10 and the older sludge reservoirs are located 15–16 m, 15–20 m and 20–35 m higher, respectively, than the “original” karst water level.

Discussion and conclusion

The comparison of the mineral content and the temperature of the water samples from the examined springs and the comparison of the obtained results

Table 2. Chemical and physical parameters of water samples of karst springs and their comparison with the standard karst water parameters (Szádeczky–Kardoss, E. 1940, 1941)

Standard solution	HCl					EDTA				
Indicator			Phenolph–thalein	Methyl orange		Murexid		Eriochromeblack T		
V (mL)	100.00	–	100.00	–	–	100.00	–	100.00	–	–
c (N)	0.10	–	0.1	–	–	0.05	–	0.05	–	–
f	1.0024	–	1.0043	–	–	1.0638	–	1.0638	–	–
E(g/gekv)	61.01	–	61.0	–	–	40.08	–	24.32	–	–
	6.12	–	6.13	–	–	2.13	–	1.29	–	–
HCO_3			Phenolph–thalein alkalinity	Total alkalinity	Temporary hardness	Ca^{2+}		Mg^{2+}		Total hardness
Date	*11.01.2013*					*11.01.2013*				
	V(mL)	c (mg/L)			dGHo	V(mL)	c (mg/L)	V(mL)	c (mg/L)	dGHo
I.	6.45	394.5	0.0	6.5	18.1	4.90	104.5	2.60	33.6	22.3
II.	6.35	388.3	0.0	6.5	17.8	4.85	103.4	2.60	33.6	22.3
III.	6.35	388.3	0.0	6.4	17.8	4.85	103.4	2.95	38.2	23.2
IV.	5.65	345.5	0.0	5.7	15.9	6.40	136.4	3.20	41.4	28.6

Table 2. (Continued)

Date	*18.01.2013*					*18.01.2013*				
I.	6.20	3792	0.0	6.2	17.4	4.65	99.1	2.80	36.2	22.2
	6.35	388.3	0.0	6.4	17.8	4.80	102.3	2.75	35.6	22.5
	6.30	385.3	0.0	6.3	17.7	4.70	100.2	2.90	37.5	22.6
	6.28	*384.3*	*0.0*	*6.3*	*17.6*	4.72	100.6	2.82	36.42	*22.4*
II.	6.15	376.1	0.0	6.2	17.3	4.75	101.3	3.30	42.7	24.0
	6.15	376.1	0.0	6.2	17.3	4.75	101.3	2.80	36.2	22.5
	6.15	376.1	0.0	6.2	17.3	4.75	101.3	2.95	38.2	22.9
	6.15	*376.1*	*0.0*	*6.2*	*17.3*	4.75	101.3	3.02	39.0	*23.1*
III.	6.45	394.5	0.0	6.5	18.1	4.80	102.3	2.85	36.9	22.8
	6.40	391.4	0.0	6.4	18.0	4.80	102.3	2.85	36.9	22.8
	6.40	391.4	0.0	6.4	18.0	4.75	101.3	2.90	37.5	22.8
	6.42	*392.4*	*0.0*	*6.4*	*18.0*	4.78	102.0	2.87	37.1	*22.8*
IV.	6.25	388.3	0.0	6.4	17.8	6.85	146.0	3.20	41.4	29.9
	6.20	379.2	0.0	6.2	17.4	6.90	147.1	3.15	40.7	29.9
	6.30	385.3	0.0	6.3	17.7	6.90	147.1	3.15	40.7	29.9
	6.28	384.3	*0.0*	*6.3*	*17.6*	6.88	146.7	3.17	41.0	*29.9*
Date	15.02.2013					15.02.2013				
I.	5.80	355.4	0.0	5.8	16.3	4.70	100.2	2.95	38.2	22.8
	5.80	355.4	0.0	5.8	16.3	4.65	99.1	3.00	38.8	22.8
	5.85	358.4	0.0	5.9	16.5	4.65	99.1	3.00	38.8	22.8
	5.82	*356.4*	*0.0*	*5.8*	*16.4*	4.67	*99.5*	2.98	*38.6*	*22.8*
II.	5.90	361.5	0.0	5.9	16.6	4.60	98.12	2.75	35.6	21.9
	5.95	364.6	0.0	6.0	16.7	4.75	101.3	2.70	34.9	22.2
	5.95	364.6	0.0	6.0	16.7	4.75	101.3	2.60	33.6	21.9
	5.93	*363.5*	*0.0*	*5.9*	*16.7*	4.70	*100.2*	2.68	*34.7*	*22.0*
III.	6.00	367.6	0.0	6.0	16.9	4.85	103.4	2.80	36.2	22.8
	5.95	364.6	0.0	6.0	16.7	4.70	100.2	2.80	36.2	22.3
	5.95	364.6	0.0	6.0	16.7	4.65	99.1	2.85	36.9	22.3
	5.97	*365.6*	*0.0*	*6.0*	*16.8*	4.73	*100.9*	2.82	*36.4*	*22.5*

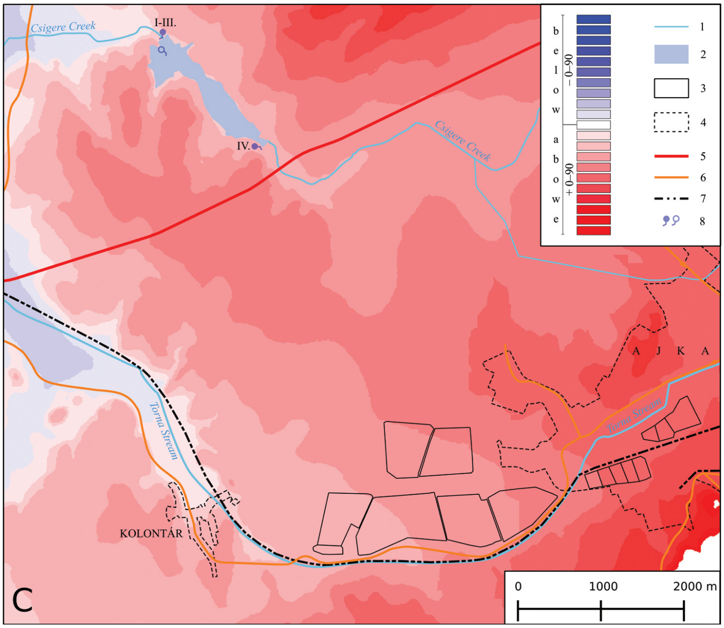

Fig 6. The height of the original karst water level (Jaskó, S. 1959) comparing to the DEM of the surface (area 'C' inside *Fig. 3*). – 1 = water course; 2 = water reservoir; 3 = sludge reservoir; 4 = residential area; 5 = primary road; 6 = secondary road; 7 = rail road; 8 = karst spring (Coloured chart: the height values of the original karst water level comparing to the DEM.)

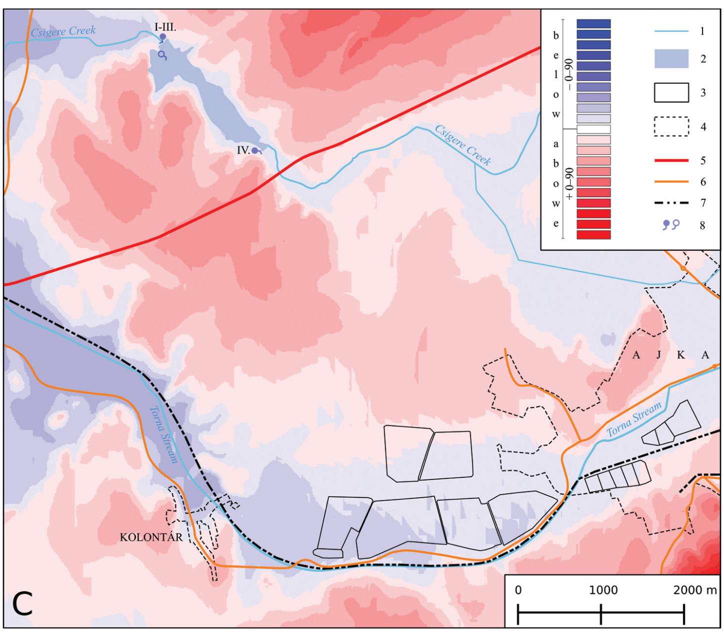

Fig 7. The height of the original karst water level (Csepregi, A. 2007) comparing to the DEM of the surface (area 'C' inside *Fig. 3*). – 1–8: For explanation see *Fig. 6*.

with earlier data undoubtedly prove the deep, karstic origins of the springs. It is even more obvious if we compare the obtained data to the low mineral content of the shallow springs in the Tatra Mountains (Żelazny, M. *et al.* 2012). The mineral properties of spring Nr. IV also underline that some of its properties being different from those of other springs can be explained by the different bedrocks.

The water chemistry results match the observations made during geomorphologic mapping and field measurements. Earlier spring activity is proven by the spring limestone visible on the sides of the valley of Csigere Creek. When the bed of the stream deepened, spring activity might have relocated to lower areas. The lowering of karst water level due to mining must have played a significant role in the drying up of the springs, however, it is impossible to determine the location of the old springs. The geomorphological situation of the recent springs and the sinter barriers all suggest that spring activity in the examined area is only a few years old. We must note, however, that Northwest from the Széki Reservoir, the leaking of water is extensive but sampling and measuring are not possible due to the conditions of the area at the moment.

To provide some data on the topic of refilling karst water system, we used a map comparing the prior karst water level and DDM. The 10 m or larger height difference between Jaskó (1959) and Csepregi (2007) type karst water isohypses posed a problem. Scientific knowledge about the hydro-geological conditions of the karst water system between the creation of the two models has greatly increased in the almost 50 years, so the later map is probably more accurate than the previous one. It is proven by the position of the springs of the Széki Reservoir.

As all the springs originate multiple meters below the calculated original karst water level, we can claim that the karst water system has been refilled up to the height of the springs (180–190 m a.s.l.) or even higher. We can only extrapolate that value to the entire karst water reservoir only with restrictions, there is a poor availability of research data concerning the area.

Outlook

The refill of the karst water system and the rejuvenation of the dried up karst springs will have an increasingly intense effect on the rest of the mountain range, so their investigation is a national economic interest. Another reason is that the rise of the water level can have some unexpected negative or even catastrophic consequences besides the positive ones. The potential negative effects will take place rather along the lines of the increased number of sinkholes and the valleys of sudden floods caused by the rise of the karst water levels (Waele, J.D. *et. al.* 2011) and not in the human-made surroundings causing damages in the built environment.

One of the already affected areas is the town of Tata where the return of 30–40 karst springs, which was significant before the drop in water level, is endangering the residential buildings of an area populated during the decrease of water level (Ballabás, G. 2004).

The volume of the springs and the rejuvenation of springs in higher locations (Tóth, M. 2002; Horváthy, L. and Lénárt, L. 2009) further increase the size of flooded areas and the number of damaged buildings. The general rise of karst water level will affect many towns in the mountains, therefore the re-examination of buildings and the review of flood prevention measures created during the time of lower water levels is more and more important.

The study was not aimed to reveal the reasons of the catastrophic events at the Ajka mud-reservoir, however, the partial refill of the karst water reservoir and the rejuvenation of karst springs can explain the high levels of underground water and the increased water supply in the reservoir and in its surroundings (Mecsi, J. 2012; Turi, D. *et al.* 2013). Since the compartments storing the mud are in the valley of the Torna Stream, below the „original" karst water level, more springs can be expected to appear. Due to the fact that there are no effective defences, the surface water removal system created by Schweitzer, F. (2010) should be used again. It could help relieve the burden caused by the leaking surface water in the area.

A positive effect of the rise in karst water levels is the stabilization of the spring volume of Hévíz lake, the refill of the cave lake in Tapolca, the rejuvenation of the Fényes springs in Tata and many others, and the increase in the volume for the hot water springs of Buda. All these provide economic benefits through tourism.

The water level of Lake Balaton has dropped considerably, approximately by 70 cm, due to the dry years between 2000 and 2003 (Somlyódy, L. 2005). Our research was conducted in the Transdanubian Mountains to apply the results of the investigation of karst water in case of Lake Balaton, namely, in respect of the raise of water level. However, that idea was rejected mainly because of the natural refill of the lake and also because of the small amount of available karst water and the potential negative side effects of the process (Somlyódy, L. and Honti, M. 2005; Tombácz, E. *et al.* 2005).

The studies have discovered, though that karst water does not influence the water quality of the lake negatively (Simonffy, Z. 2005). During the lowering of karst water level related to mining, streams carried water to the lake draining the water in mines. The travertine in Balatonfüred, the hot springs at the ship factory in Balatonfűzfő and the aforementioned streams prove that Lake Balaton was the base level of erosion for karst springs. The volume of the springs will rise with the karst water level which will influence the water level and the quality of Lake Balaton positively.

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Hungarian standards (MSz)

International standards (ISO)

AVAILABLE!

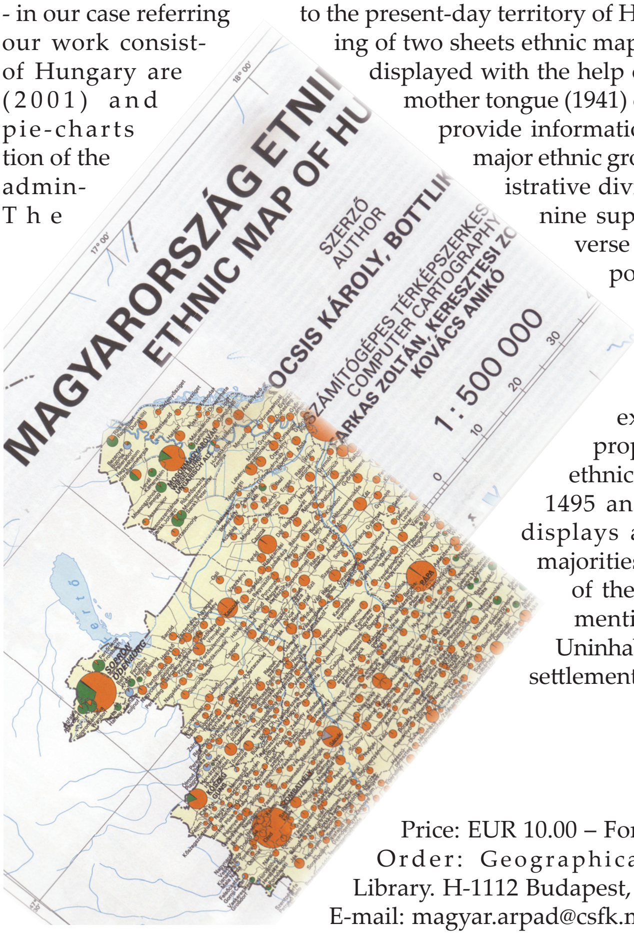
Ethnic map of Hungary 1941 + Ethnic map of present territory of Hungary 2001

Scale 1:500 000

Authors: KOCSIS, K. and BOTTLIK, ZS.

Geographical Research Institute, Hungarian Academy of Sciences, Budapest, 2009

The latest (eighth) piece of ethnic map series of the Carpathian Basin was an attempt to draft the changes that have taken place in the ethnic structure during the past five hundred years as well as to display its present state with the help of ethnic maps and a chart - in our case referring to the present-day territory of Hungary. On the front pages of our work consisting of two sheets ethnic maps of the present-day territory of Hungary are displayed with the help of pie-charts, based on ethnic (2001) and mother tongue (1941) data. Population-proportional pie-charts provide information on the territorial distribution of the major ethnic groups and on the contemporary administrative division.



The nine supplementary maps on the reverse show the lingual-ethnic composition of the present-day territory of Hungary in 1495, 1715, 1784, 1880, 1910, 1930, 1941, 1990 and 2001 respectively. The chart here explores the quantitative and proportional changes of the main ethnic groups' population between 1495 and 2001. The series of maps displays absolute or relative ethnic majorities only in the inhabited areas of the settlements which had been mentioned in the source referred. Uninhabited areas with no permanent settlements are shown as blank spots.