HYDROGEOLOGICAL INVESTIGATION OF THE GARADNA CATCHMENT AREA

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ABSTRACT

Generally, karstic aquifers are good drinking water resources providing high quality water. But these types of aquifers are sensitive to contamination and continuous monitoring is necessary. Monitoring provides a better knowledge of karst systems. Since 1992 there has been a continuous water level observing system in the Bükk. The elements of this system are water production wells, observation wells, springs and caves. This system also works as a quantity monitoring system and it can help the activities of waterworks companies.

In 2013 a hydro chemical investigation began in the Garadna spring where calcium, magnesium, sodium, potassium were determined from the collected water samples. There is continuous discharge and conductivity measurement during the spring from the end of July and continuous measurement from November 2013. During this summer we could develop a field and a laboratory measuring protocol. In our research we will compare the new hydrochemical data with water level, conductivity, temperature and discharge data.

INTRODUCTION

The investigated Garadna Spring is located in the center of the Bükk Mountain at the NE part of Hungary. The spring is the main recharge source of the Garadna Stream running through in the Garadna Valley. The spring discharges from the Hámor Dolomite Formation which is a Triassic medium karstified dolomite (MAFI, 2005). The water catchment area of the spring is located on the Bükk Plateau. The two ponor caves of the spring are the Jávorkút and the Bolhás cave which were developed in the well-karstifiable Fehérkő Limestone Formation (Figure 1). Also water tracing tests prove that the most part of water entering the spring originates from the Fehérkő Limestone Formation. The rock of this formation is a bright grey, massive, banked, platform facies limestone (MAFI, 2005).

In May of 1996 a continuous water level and water temperature register equipment was installed in the Garadna Spring. This monitoring point serves data about the mechanism of water level recession from the last 16 years and it is one of the main elements of the Bükk Karst Water Level Observing System. The basic measuring points of this system were installed in 1983 and digital pressure logging were added to the system in 1992 (Lénárt, 2006). Nowadays, the water level and temperature data are registered in production wells, observing wells, in caves and in springs. The measuring points cover the whole area of the Bükk Mountain which is one of the main benefits of the Bükk Karst Water Level Observing System because we can compare data from different measuring points (Darabos & Lénárt, 2008, Szűcs & Horne, 2009).
MATERIALS AND METHODS

The construction of measurements was based on previous results of investigations. The reaction time of the Garadna Spring is some hours which means that the raise of water level is experienced 4–5 hours after rain event. The pressure transfer always happens in the interval of 24 hours in every investigated case. The flood crest is generally 2 days after rain (it changes between 1–3 days) (Darabos & Lénárt, 2008). About the relatively quick reaction for rain the spring was sampled in every 3 and half hours into the twenty-four 1 liter bottles of water sampler equipment. The collected samples were treated with nitric acid and they were transported into the laboratory at almost the same time occurring every week.

The most common ions in karst water are usually analyzed by titration, ion chromatography (IC), UV/VIS spectrophotometry and less frequently by atomic emission or absorption spectrophotometry (AES or AAS) (Hunkeler & Mudry, 2006).

Because of huge number of sample the atomic adsorption spectrophotometer was applied for analyzing. Generally the analysis of alkali and the alkali-earth metals are simple with AAS because they have strong sign and the equipment is sensitive enough for that. We had problems with analysis of calcium because it had interferences with phosphate, sulfate, aluminum, and silicon. In our samples the presence of sulfate caused interferences. But it could be largely controlled by adding 10 g/L La as chloride (Welz & Sperling, 1999).

Another new equipment in the Garadna Spring is the ultrasonic flowmeter which measures the mean velocity of flow every 15 minutes. Unusually the instrument has only one sensor which uses continuous wave Doppler technology. For calculations water level data was also needed so in July of 2013 a new DATAQUA sensor was installed in the spring, which measures water level, water temperature and conductivity. In order to calculate the discharge we determined the relationship of water level and the cross-section.
flow where the flowmeter sensor was installed. After determination of function of water level and cross-section flow area the calculations were simple.

RESULTS
Results of chemical and correlation analysis

The chemical data was analyzed and also compared with water level, temperature, conductivity and precipitation data. In this article only the main correlations and relationships are presented. First of all the Ca\(^{2+}\) concentration, Ca/Mg ratio and the precipitation data were plotted on a diagram. Ca-concentration has a lot of outlier data but overall the data line shows a slow decreasing trend. The mean value of the whole dataset is 92 mg/L (Figure 2).

![Diagram of Ca-concentration – Ca/Mg ratio – precipitation and trend lines](image)

*Figure 2. – Diagram of Ca-concentration – Ca/Mg ratio – precipitation and trend lines*

In case of precipitation the Ca concentration rises at first then decreases and returns to the average value. A possible explanation of increasing of concentration is the pushing out of the well mineralized water from the karst system. During rainless period the karst water has a lower seepage velocity which results more contact time to solve minerals. After rain event the infiltrated water increases the water level and it causes higher seepage velocity and higher hydraulic gradient. This kind of water spends less time in the system and it contains less Ca so the concentration decreases. The length and rate of changes depend on several factors. These factors are the geometry and size of the karst system, the distribution of rainfall, the time when rainwater appears in the spring, the ratio of dilution and the chemical characteristics of the water held in the system.
The shape of the graph also gives information about the karst system. A graph with sharp positive and negative peaks represents a well karstified system, which system is able to deliver diluted and infiltrated components to the spring (Hunkeler & Mudry, 2006).

Rainfall causes small decrease in Mg concentration, and in long term rainless period Mg shows a slow decreasing trend (Figure 3). It can be also seen, when Mg concentration decreases, the Ca/Mg ratio increases ($R^2 = -0.7$).

**Figure 3.** – Diagram of Mg concentration, Ca/Mg ratio – precipitation and trend lines

**Water level – discharge**

**Figure 4.** – Relationship between discharge and water level, equations of linear and polynomial trend lines, $R^2 = 1$
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While chemical analysis of water samples stopped at the end of March 2014, water level, temperature, conductivity measurements and discharge data calculations continued.

First of all we determined the mathematical function between water level and discharge data. For this purpose we plotted the two data sets and fit linear and polynomial trend lines and determined their equations (Figure 4).

\[ Y = z - \text{water level [mABSL]} \]
\[ X = Q - \text{discharge [m}^3/\text{s]} \]

Equation of linear trend line: \( z = 1.05891576 \cdot X + 495.9143483 \).
Reordered to discharge:
\[
Q = \frac{z - 495.9143483}{1.05891576}.
\]

Equation of polynomial trend line: \( z = 495.880847 + 1.77769087 \cdot X - 2.744091453 \cdot X^2 \).
Reordered to discharge:
\[
Q = 730243.6717 - 2945.230605 \cdot z + 2.969688075 \cdot z^2.
\]

After reordering the equations of the trend lines we calculated discharges from them in both cases. Then we compared the calculated and the real discharge data as Figure 5 shows. Between two calculated data sets and real discharge data correlation coefficient is \( R^2 = 0.97 \), which means very good correlation.

![Figure 5. -- Calculated discharges compared to the real discharge (\( R^2 = 0.97 \))](#)
Calculated and real graphs correlate well and correlation coefficient is also excellent (Figure 5). Based on this information we think – although precise discharge data cannot be calculated – the trend can be determined from water level data.

**Determination of base discharge of Garadna Spring, calculation of discharge data from 2001**

We have daily water level data provided from 2001 until today, which were measured and registered within the framework of the BükkKarstwater Level Observing System. From these data we calculated discharge data as it was written in the previous chapter.

![Figure 6](image)

*Figure 6. – Linearly and exponentially calculated discharges from 2001 to 2014 \((R^2 = 1)\) and base discharge \((0.05 \text{ m}^3/\text{s})\)*

Linearly and exponentially calculated discharge graphs fully cover each other, there is no difference between them, their correlation coefficient is \(R^2 = 1\) (Figure 6).

According to water level data of years the Garadna spring has a constant water level which is 495.96 meter above Baltic Sea level (maBSI) but it could change between 495.9 maBSI and 496 maBSI. After rain event the precipitation increases the water level of spring so the precipitation is superimposed on this water level but it decreases to the mentioned constant water level in the rainless periods. The discharge of spring on this characteristic water level (495.96ma BSI) is 0.05 m³/s.

So it can be established that the base discharge of the Garadna Spring is about 0.05 m³/s, which marked in Figure 6 with a blue line. In long rainless periods – as in 2011 and 2012, when the annual precipitation was 56 and 645 mm, respectively – for longer or shorter
periods discharge was even lower, because recharge from the micro fissure system was worse.

**Determination of water type by using Piper-diagrams**

A piper-diagram was used to visualize chemical data. By using water chemistry data the chemical type of the water can be determined.

For this method we collected water samples at four different times, which samples were not treated by acid and all the necessary chemical measurements were performed within 24 hours.

The results are presented and summarized on Figure 7.

![Figure 7. Results represented on Piper-diagram](image)

From aspect of cations the type of water is 'Ca$^{2+}$ type' because of the low Na$^{+}$ and Mg$^{2+}$ concentration. From aspect of anions water belongs to the '$\text{HCO}_3^-$' type' because of low concentration of Cl$^-$ and SO$_4^{2-}$ (Figure 7).

Based on overall results the chemical type of the spring water is obviously 'Ca$^{2+}$-Mg$^{2+}$-$\text{HCO}_3^-$ type'.

The results of this method are important because the spring discharges from dolomite but the main part of it is water catchment spreads on limestone. Based on the diagram the
rate of Mg is less than 5% so the type of water is 'Ca type'. The chemical type of water originated by the Fehérköi Limestone Formation.

Additionally we calculated the saturation index of calcite and aragonite by PHREEQC modeling program. In case of SI=0 means equilibrium, SI>0 water is oversaturated SI<0 water is undersaturated from aspect of given phase.

Table 1

<table>
<thead>
<tr>
<th>Date</th>
<th>SI$_{calcite}$</th>
<th>SI$_{aragonite}$</th>
<th>Conductivity[mS/cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>17/03.</td>
<td>0.17</td>
<td>0.02</td>
<td>0.422</td>
</tr>
<tr>
<td>07/04.</td>
<td>0.14</td>
<td>-0.02</td>
<td>0.359</td>
</tr>
<tr>
<td>14/04.</td>
<td>0.14</td>
<td>-0.02</td>
<td>0.339</td>
</tr>
</tbody>
</table>

Table 1 shows that saturation index of calcite over zero is in all cases, it means, that spring water is oversaturated and precipitation can be expected what is supported by literature and we also experienced it during our measurements.

CONCLUSIONS

The last few months were a very rainless period in the Bükk Mountains. So the chemical analysis of these months only serves data about general chemical composition of spring. The hypothesis is that in our work the change of chemical composition of karst water after rain. In this period we did not have a significant rain event which could confirm our hypothesis.

The continuous monitoring of spring will be completed with mixed investigations. Now we can prove that the Garadna spring has inflow from other water body. We will collect water sample from lower point of the ponor cave and we will try to sample other ponor caves of the spring. After analysis of water samples data will be used for geochemical modeling. Additionally it is planned to analyze the strontium content of water samples of caves to identify the occurred underground water inflow.

Due to the high correlation of discharge and water level we can calculate the discharge data from the water level data of last 17 years according to water level-discharge function.

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REFERENCES


