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COMPARATIVE ANALYSIS OF THE FLOW ACTIVITY OF THE HOMOLJSKA POTAJNICA INTERMITTENT SPRING

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Abstract: Homoljska Potajnica belongs to the type of a very rare, intermittent or rhythmic springs which appear exclusively in karst areas. It is one of the three known springs of this type in Serbia, while it is believed to be only about fifty of these in the rest of the world. As a rare karst and natural phenomenon, Homoljska Potajnica was a subject of interest for numerous researchers and geomorphologists in Serbia. Due to a very complex problem of occurence and the principle of functioning, to get the reliable data of how intemittent springs work, it is neccesarry to provide a continious observations, ussually in a long term period. This paper presents the results of the measurements of spring's flow activity and water discharge, taken in 2012. and 2013. These were carried out for comparison with the results of previous research, with an aim to determine possible changes in dynamics and mechanisms of spring's functioning in the past. One of the goals is to relate the annual precipitation regime with the intensity and frequency of spring activity, to try to determine the specific model of the spring's functioning. Another goal is to emphasize the need for continious observation in order to obtain the relevant data about the evolution of this rare natural phenomenon.

Key words: Homoljska Potajnica, intermittent springs, flow activity, water disharge, karst hydrography

Introduction

Intermittent springs (rhythmic springs; in Serbian: potajnice, mukavice) belong to a rare type of karst springs which are characterized by intermittent water discharge, in intervals that may last from several minutes to several hours, days or even months (Bonacci & Bojanić, 1991). Despite the fact they exist exclusively in karst terrains, these springs are rare, compared to all other hydrographical karst phenomena.

A specific functioning of intermittent springs is explained by the theory of siphon (Lazarević, 2000). There is a presumption of one or more cavities in karst underground which are connected with the surface by the siphon channel (ascending–descending channel). This underground “tank” fills those filters with

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water through the underground channels and cracks in limestone, until the water level in the "tank" reaches the curve level in siphon channel. Water in the channel then starts to overflow and flows by gravity down the descending limb of the siphon channel, thus causing the discharge of underground "tank". In the moment of the overflow, due to the sudden decrease in pressure, in the top of the siphon channel the vacuum is formed, which sucks the water out and it continues flowing by gravity and hydrostatic pressure of water in the "tank". Water, which flows down the descending limb of siphon channel, pushes the air in front of it which often produces the sound of gurgles just before the water shows at the topographic surface. The emptying of the "tank" will be happening until the moment when the water level in it drops down to the beginning of the ascending limb of the channel. Then again the air enters the siphon channel and the water discharge stops. This is followed by the water refill during which the rhythmic spring is not active, until a certain moment when the process repeats by the same principle. However, although this explanation is relatively simple, the mechanism of intermittent springs functioning in nature is often much more complex and varied. This is affected by many factors such as: the existence of entire system of underground supplying channels or more underground cavities with different volumes and unequal discharge periods, that work by the principle of communicating vessels; underground bifurcation phenomena, in cases when in vicinity of intermittent is a permanent spring too; morphology changes of supplying underground channels; annual precipitation regime, etc.

In wet season, when water inflow into the underground cavity is greater than the amount of water that can be discharged through the siphon channel, the intermittent spring will work as a permanent spring, without the characteristic interruption. As opposed to that, in dry season intermittent springs can completely dry out for a longer period. The amount of discharged water during one activation cycle depends primarily on the volume of the "tank", but also on the connection between underground cavities. The time needed for emptying the "tank" also depends on its volume, as well as on diameter of the siphon channel. This is why the problem of studying intermittent springs is often very complex and requires a detailed and continuous observation of multiple parameters simultaneously.

Based on a flow activity, Gavrilović (1967) distinguished three types of intermittent springs: 1) permanently intermittent, 2) seasonally intermittent and 3) pseudo–intermittent springs.

Homoljska Potajnica is one of the three known springs of this type in Serbia[2]. It is located in eastern Serbia, on the southern slopes of Mt. Homoljske Planine and northern edge of Žagubica basin, in the Valja Mori river valley which belongs to the Mlava river basin. More precisely, the spring is located on the left side of the valley of Potajnica creek, about 9 meters above the creek bed, on the slopes of Mala Škljova (Školja) hill. Administratively, the spring belongs to Žagubica municipality and the village of Laznica. From Žagubica it is about 12 kilometers to the north, but from Laznica and Selište village is just about 6 and 5 kilometers to the north, respectively. Geographical coordinates are 44°16'47"N and 21°49'01"E (+/- 10 m). Altitude is about 465 meters a.s.l, which is 53 meters higher compared to Gavrilović's data (1967). Potajnica can be reached by the gravel road from Selište village through the Valja Mori river valley, or by the path which leads over the Djalu Mare saddle, between the Valja Mori and Valja Mare valleys.

Geologically, northeastern part of Žagubica basin, where Homoljska Potajnica is located, consists of Paleozoic rocks – metamorphic sandstone, phyllite and schist (shale, slate), while the geological formations of Mesozoic age in this part of the basin occur only sporadically (Miljković, 1992).

Potajnica itself is located at the contact of one such party of Jurassic reef limestone (Tithonian) and Paleozoic shale rocks (Ordovician). The upstream part of the Potajnica creek valley is formed in schist rocks, but the downstream part consists of limestone breccias, as the entire Valja Mori river valley. The contact of these two geological formations is presented by a fault which can be noticed by many saddles in relief between the valleys of Potajnica creek and the nearby Ponorski creek (Gavrilović, 1967).

Previous studies of Homoljska Potajnica

A complex study of Homoljska Potajnica intermittent spring in the past was done by relatively small number of geographers. Jovan Cvijić was the first who did a scientific observation of the spring, on May 21st 1893. He described the spring as a small crack in limestone which is connected by a ravine with the Potajnica creek bed. The crack itself widens inside the limestone underground and splits into three different channels 10–30 cm in diameter (Cvijić, 1896). During his observation, water eruptions have occurred in intervals of 39 – 49

[2] The other two are Promuklica and Kojin izvor, in southwest Serbia. Once, there was a fourth spring of this type, named Kučevska Potajnica. Unfortunately, after the Second World War the quarry was formed in its very vicinity so this spring lost its character of intermittent. Today, it is just a normal, permanent spring (Lazarević, 1990).

minutes, with duration of 19–23 minutes. Cvijić believed that duration of water eruptions, as well as the amount of discharged water, should always be the same since they depend on volume of the underground cavity, while duration of cavity filling depends on annual precipitation regime. He explained that certain defferences in duration of the water eruptions can occur due to possible measurement errors, but still aware that they could be real. Later studies, however, have shown that the way of spring functioning is not as simple as Cvijić thought.

In the period 1958–1962, Jovan Marković did a few one-day observations of Potajnica 's activity. Observations took place at the end of July and at the begining of August. Marković' data on the duration of water eruptions range from 19 to 25 minutes, so they are very similar to the data Cvijić noted. However, he rejected the measurement errors as a possible cause of unequal duration of the eruptions, but made a different conclusion - that in karst underground there is entire system of connected cavities and channels, so called secondary Potajnica, which are being filled and emptied in unequal intervals (Marković, 1963). During Marković's observations, water eruptions have occured at intervals of 3.5 – 4 hours, which is explained by the fact that the observations were made in a season when the water inflow to the karst undergound is less and slower than in May, when Cvijić made his observation. Marković also made the first calculation of the amount of discharged water during one eruption, on which Potajnica discharges aproximately about 4 dm^3 of water per second, which means between 4 000 and 5 000 liters per eruption. On this basis, he calculated the volume of the underground cavity, which is about 5 m^3. Of course, this data can never be confirmed because the actual volume is impossible to determine since there is no way to find out what is the volume of the cavity above the water filling level as well as the volume of the cavity that is always flooded (Marković, 1963).

In the period between 1963 and 1966, Dušan Gavrilović has done the most complex study of Homoljska Potajnica so far. By the stories of local villagers, Gavrilović determined a strong influence of regressive erosion on spring surroundings, compared to Cvijić time. Also he found an underground connection between Potajnica and nearby Ponorski Potok creek from which the spring is partially fed. Analyzing the Potajnica flow activity by sporadic measurements and observations in four-year period, he noted a very different data on durations of water eruptions as well as in intervals between them, even in the same months each year. Thus he concluded that in the rainy month spring can sometimes work as a normal, permanent spring, but in the dry months it can dry out for more than 24 hours. Gavrilović also noted another spring, small by volume but permanent leakage from the same crack from which Potajnica flows out, with the constant water discharge of 0.02 dm^3/s. By calculating a total amount of discharged water during one eruption he recorded the amount of 1400 dm^3, which is considerably less compared to Marković' data from 1963. The period of discharge was aproximately the same (Gavrilović, 1967).

Interesting data in determining the spring dynamics was noted by Ljupče Miljković, in the summer of 1980. During his observations, the water eruption lasted considerably shorter than ever before (14-16 minutes), while filling the "tank" between eruptions was regular for this time of year. The maximum discharge was about 1.7 dm^3/s (Mirković & Miljković, 2006). From these data it can be concluded that the amount of discharged water was significantly reduced compared to all previous observations.

The latest documented observation of the spring dynamics was done by the members of the Society of young researchers "Branislav Bukurov" from Novi Sad, in the summer of 2005 and 2006. Both measurements showed a record-long duration of water eruptions. On August 5th, 2005, two eruptions lasted for 1 hour and 7 minutes each, while filling of the "tank" lasted up to 7 hours (Mirković & Miljković, 2006).

Homoljska Potajnica research methodology

In the years of 2012 and 2013, several observations of the spring activity were made in order to determine possible rules of how this rhythmic spring works during the periods with different precipitation regime.

The research methodology included a variety of techniques and methods that can be divided into those that were used in the field and the others that were used in the laboratory.

Field methods were used in resolving the following issues:

- The water discharge measurement, by precise sampling of the flowing water, in equal intervals and duration, throughout the entire eruption. Tools used in this process included: a large plastic container for collecting the water samples; plastic beaker of 1 liter volume for measuring the collected water amount; a stopwatch for measuring the intervals for water sampling; pre–prepared tables for input of the measurement results. In order to obtain reliable and accurate data, the measuring process had to be done perfectly. This is why measuring procedure had to involve four people with clearly assigned duties.

- The analysis of some physical and chemical characteristics of spring water by waterproof handheld multimeter 18:52:01. The water samples were taken with sterilized cans and tested with previously calibrated electrodes. Thus the data on the temperature, conductivity and pH of water, the percent of dissolved oxygen and dissolved solids in the water were obtained.

Laboratory methods included the analysis and computer processing of the results in the form of mathematical calculations and graphics, by using statistical software Past 2.17 and Microsoft Excell.

Results of the recent observations of Homoljska Potajnica

From July 18th to July 21st 2012, a continuous observation of Potajnica was made, with a goal to determine the flow characteristics of the intermittent spring, after a long period without precipitation. The season in which the observation was made was aligned with those in which most of the previous observations in the past were made, in order to get the adequate comparison for the data obtained.

The observation of the flow activity started at 8 am. Since there was no fresh signs of a recent flow, it was concluded that the spring was not active for at least 3 or 4 hours before the observation began. There was only a tiny leakage of 0.016 dm³/s. The first water eruption occurred at 20:58, after the observed pause of 13 hours, which definitely lasted longer. What was immediately noticed was that the eruption was not preceded by any gurgling that Gavrilović mentioned (1967), and certainly not by "…crashing noise which creates a bad feeling and impression that the hill is going to burst…" as Marković described it (1962). Everything one could hear was just a quiet murmur at the moment when the water already showed at the spring hole.

By taking samples of the water flow, on every 3 minutes in duration of 4 seconds, during the entire eruption, the precise data on water discharge were provided. The water eruption stopped at 22:20 which means it lasted about 1 hour and 22 minutes. The end of eruption was considered to be the moment when the water flow evidently transformed to a leakage as it was before the eruption. Detailed measurements, however, have shown that at that moment the water discharge was 0.06 dm³/s. Decrease from 0,06 dm³/s to the constant discharge of 0.016 dm³/s have lasted for hours, but this period was not included in eruption duration since it was attributed to the gravitational outflow and draining of the siphon channel(s). The analysis of the water discharge diagram (Figure 1a) has shown that it increases linearly and reaches its maximum between 10' and 13' from the eruption start, which is about 2.8 dm³/s.

Continuous decrease follows, which clearly lasts longer than one hour and as precise measurement showed, actually much longer.

By using the interpolation method, it was determined that during 1 hour and 22 minutes of outflow, the discharged water amount was about 3800 dm^3, which means about 0.8 dm^3/s on average.

The next eruption occurred after the pause of 28.5 hours, on July 20th at 01:30, quietly as the previous one. By identical measurement process, new data were obtained (Figure 1b). This time the water eruption lasted 1 hour and 20 minutes and it was finished at 02:50. It means a couple of minutes shorter than the previous one, but the trend was the same. Total amount of discharged water was about 3760 dm^3.

Since the data obtained from two following eruptions were very similar, certain differences between them can be a result of imperfection of the measurement process itself, as well as the fact that it was carried out in the middle of the night, in the low visibility circumstances, when the end of eruption is much more difficult to assess than on the daylight.

Based on the length of previous pause between eruptions, since the weather conditions were unchanged, it was assumed that the next pause should last at least 28 hours. This was confirmed in the next 37 hours, when the observation had to be stopped for technical reasons and Potajnica still did not activate. The interval between two eruptions was extended for entire 9 hours, and probably more.

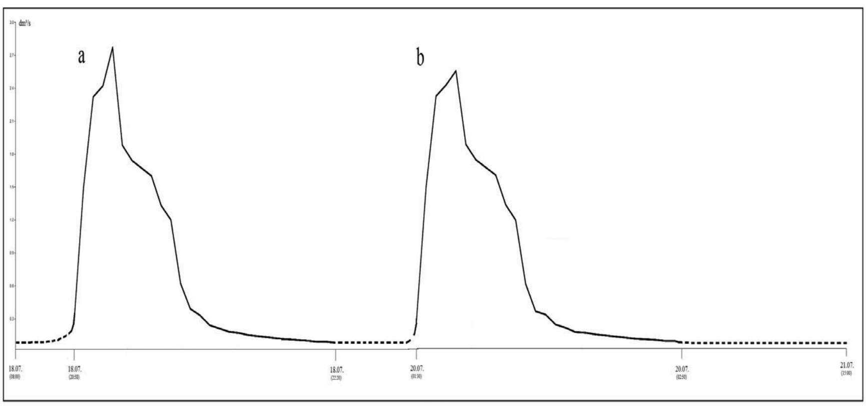

Figure 1: Water discharge diagram of Homoljska Potajnica on July 18th (a) and 20th (b), 2012

Based on two precise measurements which showed very similar results, the final model of Homoljska Potajnica activity cannot be determined, but it could be assumed that in extremely dry period, as was the summer 2012, Potajnica "works" in a relatively stable manner. The main characteristics such as the duration of water eruptions, dynamics and the discharged water amount are almost equal, except the pause that is directly related to the length of dry period.

Thus it can be assumed also that in dry season Potajnica works much simpler than in wet season. This can be explained by the following fact: in the wet season much more underground cracks and channels in karst are active compared to the dry season. These cracks are full of water and this makes the "tank" filling process much more complex than in dry season, when most of these are empty and when Potajnica works on the basis of simple filling and emptying of one final underground reservoir.

Since the next few weeks passed without rain and by knowing the trend of how intervals between eruptions extend, it is reasonable to believe that the pause between eruptions in August lasted for few days or even weeks.

The facts at the end of four–day studies of Homoljska Potajnica were the following: during 103 hours of constant observation, the spring was active only twice, with approximately the same rhythm and duration, as well as the water abundance (Table 1).

Table 1. Activity of Homoljska Potajnica in the period 18 – 21.07.2012

Date	Outflow time (h)	Outflow duration (min)	Interval between two following eruptions (h)
18.07.	20:58 – 22:20	82	>13
19.07.	-	-	-
20.07.	01:30 – 02:50	80	29
21.07.	-	-	>37

Analyzing the diagrams, in both cases, an irregular decrease of water discharge between 15th and 35th minute from the outflow beginning can be noticed. There is an interesting curl on the diagrams which presents the slow-down phase in current decreasing trend. This could indicate a possible synchronized discharge of more cavities at the same time, or the interval when the emptying of the "main tank" is followed by the emptying of some smaller one, which disturbs the current trend. More detailed studies in the future should give an answer to this question.

Along with the water discharge measurements, the analysis of some physical and chemical characteristics of spring water was made. On the water sample from the tiny leakage of a normal spring, the following values are noted: Temperature of 12ºC, which is a normal groundwater temperature for this part of the year in temperate climate zone; Conductivity of 464µS; Dissolved solids about 280 mg/dm³; Dissolved oxygen about 81% or 7 mg/dm³; pH of 6.5, which corresponds with the mildly acidic to neutral water.

Physical - chemical analysis this time was not made on a sample of water collected in the underground but this should certainly be done in future in order to compare characteristics of the fluent water from the normal spring and the water that collects in the underground, especially in cases when the intervals between eruptions are so long as they were in summer 2012.

The second visit to Homoljska Potajnica took place on April 14th 2013. This time the spring acted as a normal constant spring with an average discharge of 0.8 dm³ /s. During the 7–hour observation, there was an outflow with unchanged rhythm, which was confirmed by precise measurements on each 5 minutes during the examination period. Since the observation was done in early springtime, after the snowmelt and after the few weeks of everyday rainfall, it was concluded that the water inflow to the underground “tank” on these particular days was constant and greater than siphon channel capacity. This is why the “tank” could not empty rhythmically. The constant pressure of groundwater to the siphon channel made Potajnica act like a typical karst siphon spring. This kind of spring “behavior” depends on the amount of water in karst underground which is expected to be large in this part of the year. As the dry season becomes closer, the water inflow to the underground is less and slower, so intermittent characteristics of the spring become more obvious in time.

Physical - chemical analyses of water were made too. The water temperature was 10°C, which is less compared to the previous analysis in July, but it can be considered normal, since the analyses were made in April; Conductivity value was 191,6µS which is also significantly less than in July. This could be the consequence of continuous outflow and rinsing; Dissolved oxygen level was risen to 90% or 8.3 mg/dm³, probably with the same reason as conductivity values drops; pH was 7, which is approximately the same as in previous analysis.

Another visit to Potajnica was made on July 24th and 25th 2013. For 26 hours of constant observation, the intermittent spring did not show activity at all. Since the climatology yearbook for the year of 2013 was not available in the moment when this paper was written, the comparison of the weather conditions with the year 2012, in order to determine some similarities, was not possible.

The latest observation was made on November 14th and 15th of the same year, but the spring again showed no activity. Moreover, judging by the thick layer of dry leaves near the spring hole, it can be concluded that it was not active for days. Such a long pause in this particular part of the year was never noted before.

Discussion

From the review of previous studies, based on the available data about the Homoljska Potajnica flow activity in the past 120 years, as well as the recent ones, it can be concluded that, practically, it is impossible to determine any final pattern of how this spring works and for how long its eruption lasts. The existence of more than one cavity or “tanks” which empty in unequal intervals and also the entire network of connected channels, as Marković (1963) and Gavrilović (1967) wrote, does not leave an option for determining any rules about the Potajnica activity on a daily basis. Water eruptions constantly vary in outflow duration, discharged water amount and the interval of the “tank” filling. These varieties are minimal, but very obvious.

Based on presented studies in the past, it can be noted that the duration of water eruptions can last from 14 and 16 minutes, as Miljković noted (1980), up to 1 hour and 22 minutes as the recent study showed. Due to the lack of data on the amount of discharged water in most previous studies, the adequate comparison of water eruptions cannot be made. If such data existed, it could be possible to determine the relation between the discharged water amounts during one eruption, how the water amount affects the duration of eruption, and whether it affects it at all.

Assuming that the discharged water amount during each eruption should be approximately the same, Marković data (1963) could be somehow comparable with those from July 2012. Specifically, Marković carried out data of the average water discharge of 4 dm^3/s, with duration of about 20 minutes that includes 4000-5000 dm^3 of discharged water. In recent study there are data of average discharge of 0.8 dm^3/s with duration of 1 hour and 22 minutes and the total amount of 3800 dm^3 of water. This could mean that the average water discharge has dropped about 5 times, but the same amount of water was discharged for about 5 times longer period. Based on this comparison, it could be assumed that the cause of this prolonged duration of the eruption during the latest measurement is a certain change in the morphology of siphon channel (blockage), which slowed down the outflow.

However, based on the one possible coincidence, one cannot claim that every eruption should last equally and discharge the same amount of water, since the entire mechanism of emptying the underground "tank" is obviously very complex. Therefore, future studies should confirm or disprove this coincidence. Also, some blockage is expected and normal to occur periodically, which disrupts an established rhythm of intermittent spring, thus preventing us to determine an unconditional rule in their functioning. Corrosion is a slow but a constant process that affects the morphology of underground channels and should not be disregarded.

From the previous studies it can be noted also that the pauses between eruptions could last uneven – from 39 minutes as Cvijić wrote, up to few days as recent studies proved. While these differences are understandable between the wet and dry season, it remains unclear what causes them in the same part of the year.

For this reason, by analyzing the data from the Žagubica weather station, the comparison is made between all observations in the past that were made in approximately the same period, in order to determine the relation between the discharged water amount, the frequency of eruptions and the lenght of the eruptions pause (Table 2).

Table 2. Relation between discharged water amount and frequency of eruptions

Researcher	Date	Total rainfall since the May each examining year (mm)	Pause duration
J. Marković	22.07.1958.	120	3h 50'
	01.08.1962.	125	3h 40'
D. Gavrilović	24.08.1963.	210	about 7 h
	18.08.1964.	165	> 24 h
	15.07.1966.	254	2 h 42'
Lj. Miljković	17.07.1980.	320	about 3h 25'
SYR	11.08.2005.	339	7h 36'
"Branislav Bukurov" Novi Sad	17.07.2006.	153	about 3h

By summing the average monthly values of precipitations in the period 1946–2012, it is clear that May and June are the months in which Žagubica recieves the most rainfall during the year. It is followed by the assumption that the amount of rainfall may have an impact on the activity of Potajnica in upcoming months. However, by making a relation between the average monthly rainfall values and the length of the pause duration, starting from May of each examining year, it was concluded that, based on a total rainfall amounts, there can be no rule on the pause duration length determined. Assuming that a higher amount of rainfall should cause a shorter pause between eruptions, seemingly illogical exceptions and irregularities were shown. Although it is doubtless that rainfall amount is crucial for Potajnica activity, the conclusion is that their daily regime is much more important than monthly. That kind of analysis was not made in this case.

Since Potajnica showed significant differences in its flow activity, even in the same part of the year, future studies should answer the following question: are these differences the result of some permanent changes in intermittent spring mechanism or is it just a consequence of the specific precipitation regime (drought) in the years when latest observations were made?! Such an analysis will only be possible when all needed meteorological data become available.

For solving this problem, the great importance lies in understanding the dynamics of snow melting process in springtime, as well as in better studying of karst hydrography. Also, it is necessary to start a continuous long term observation, under the same or similar conditions, as well as in different seasons, in order to collect reliable and comparable data which will help us to better understand the functioning of this rare karst phenomenon in Serbia.

References

Bonacci, O. & Bojanić, D. (1991). Rhythmic karst springs, *Hydrological Sciences Journal, Vol 36*, Issue 1, p. 35-47

Gavrilović D. (1967). Intermitentni izvori u Jugoslaviji, *Glasnik Srpskog geografskog društva, sveska XLVII*, broj 1, Beograd

Lazarević R. (1990). *Kučevska potajnica*, Zavod za novinsko – izdavačku i propagandnu delatnost, JŽ, Beograd

Lazarević R. (2000). *Geomorfologija*, Prirodno – matematički fakultet, odsek za geografiju, Banja Luka

Marković J. (1963). Homoljska potajnica, *Glasnik srpskog geografskog društva, sveska XLIII*, broj 2, Beograd

Miljković Lj. (1992). *Homolje – Geografska monografija*, Prirodno – matematički fakultet, Institut za geografiju, Novi Sad

Mirković S., Miljkovič Lj. (2006). Turistička valorizacija i zaštita Homolsjke potajnice, *Kongres srpskih geografa, Zbornik radova, knjiga 1*, str. 801 – 806, Soko Banja

Cvijić J. (1896). Izvori, tresave i vodopadi u istočnoj Srbiji, *Glasnik srpske kraljevske akademije, sveska LI*, Beograd