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# OCCURRENCE OF ALKALINE WATERS IN THE SOUTHERN APUSENI MOUNTAINS (ROMANIA) – RESULTS OF A PRELIMINARY SURVEY

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**ABSTRACT**. Consumption of alkaline water by the general population has increased over the past two decades, as certain customers value this type of water for its presumed ability to promote health. In spite of the commercial interest for natural alkaline water sources suitable for drinking purposes, relatively few scientific publications related to the occurrence of these waters are available. This article presents the results of a preliminary survey for alkaline water in the Southern Apuseni Mountains. This region has been selected as study area due to the presence of limestones and ophiolitic rocks, very often in contact with each other, both having the potential to bring the pH of natural waters to the alkaline range. A total of 78 sampling points, represented by streams, lakes, springs and dug wells have been investigated, and the physico-chemical common parameters were measured in the field. Alkaline water with pH above 8.0 has been found in almost 29 sampling points, out of which 7 points had a pH above 8.5. Most of the points were represented by surface running water. The prospective areas, as identified by this survey, correspond to Trascau Mts., and to the western (predominantly ophiolitic) part of the Metaliferi Mts. The data included in this paper may represent the starting point for a systematic survey and for a detailed study of the potential alkaline water resources in the study area.

**Key words:** *alkaline water, ophiolites, limestones, Apuseni Mountains.*

## INTRODUCTION

Natural alkaline water, generally with pH in the range 7.5 – 9.5, represents a field of growing interest for the water bottling industry, as part of the consumers consider they may provide health benefits. Although there is commercial interest in this type of water, there are relatively few published papers dealing with alkaline waters for human consumption. The chemical features of groundwater, including the pH, are strongly influenced by the type of rocks the water is travelling through, being the result of complex water-rock interactions occurring along the water pathway. Ophiolites and limestones are rocks that are recognized for their ability to confer an alkaline character to waters with which they come into contact (Etiope et al., 2017; Papp et al., 2017; Giampouras et al., 2019). The chemical composition of the alkaline waters in these cases is dominated by the bicarbonate and calcium cations (related to limestones) or magnesium (related to ophiolites). Under particular conditions, the pH may even be higher, exceeding 10.0 or even 11.0, and in this case the water becomes hyperalkaline, the ionic composition is dominated by calcium and hydroxyl, and it is not suitable for human consumption.

High pH may also occur in endorheic lakes in arid climates, which are prone to the accumulations of salts. Waters with a certain content of dissolved salts continuously or temporarily recharge such lakes, and the salt concentration is increasing as a result of the evaporation. Such particular lacustrine environments may show remarkably high values of the pH, sometimes exceeding 11.0. As an example, the Eras Lake, located in Central Spain, is a brackish to saline, highly alkaline lake, with pH up to 11.3 (Cabestrero et al., 2018). In SE Romania, Movila Miresii endorheic lake has pH values above 9.0 (Voicu et al., 2017; IBF, 1961-1973). Such alkaline lakes are suitable for bathing, and some therapeutic effects are recognized.

Taking into account the massive occurrence of ophiolites and limestones in the Southern Apuseni Mountains the geological premises for the genesis of alkaline waters are met, as shown by Nicula & Baciu (2019). Geothermal manifestations are also known in the study area (Orășeanu, 2020; Nicula et al. 2021), an aspect that could intensify the processes of water-rock interaction and increase the level of alkalinity in the water (Xia et. al., 2020).

The current study intends to identify water sources with high pH, to identify the distribution and variability of the pH values in the concerned area, and to assess the prospective zones for more detailed studies.

## STUDY AREA

Geologically, the Southern Apuseni Mountains represent a distinct portion, with particular features, of the Apuseni Mountains. The North Apuseni Mountains correspond to the outcropping area of the Tisia block, and mainly consist of medium or low-grade metamorphic rocks, with some granitic intrusions. This basement is covered by Permian-Mesozoic sedimentary formations (Săndulescu, 1984). By contrast, the Southern Apuseni correspond to the eastern Vardar mobile area (Schmid et al., 2020). They include ophiolitic units represented by tholeiites (Middle Jurassic) and calc-alkaline magmatic rocks (Late Jurassic to Early Cretaceous) (Mutihac, 1990). The tholeiitic series are present in the western part of the study area, and are dominated by basalts, intruded by gabbros and gabbro-peridotite bodies. The calc-alkaline series occur in the central and eastern part, and include basalts, basaltic andesites, and some acid rocks as dacites and rhyolites. The ophiolites are locally intruded by granitoids (Cioflica et al., 2001). The clockwise rotation of the Apuseni Mountains during the Middle Miocene led to the opening of graben-like basins on the western side of the mountains, that are filled with Miocene sediments. As a result of the extension, calc-alkaline extrusive magmatism has occurred contemporaneously (Seghedi, 2004).

All the sampling points are located in the Southern Apuseni Mountains (figure 1), predominantly along valleys, in depressionary areas. Two distinct zones were investigated. The north-eastern zone overlaps the following geomorphological units: Culmea Hășdate (P1 – P4 and P18 – P20), Colții Trascăului (P13 – P16), Trascău Depression (P5, P6 and P11, P12), Culmea Bedeleu P7, Sălciua Depression (P9), Ocoliș-Poșaga Depression (P8), Aiudului Hills (P17 and P10), Vlaha-Hășdate Depression at the boundary with Feleac Hill (P22 – P27). Most of the points (51 points in total) were tested within the southern area, north of the Mureș Valley. The geographical distribution of the investigated points, by geomorphological units, in the southern zone is the following: the Husului Mountains (P28 – P52), the Măgureaua Mountains (P53 – P59, P73 – P75 and P77, P78), the Brad Depression (P67 – P70 and P76), Găina Mountain (P71, P72), Săcărâmb Mountains (P60 – P63 and P65), and three other points (P64 – P66) towards the eastern part of the study area, in the Almaș-Bălașa Depression.

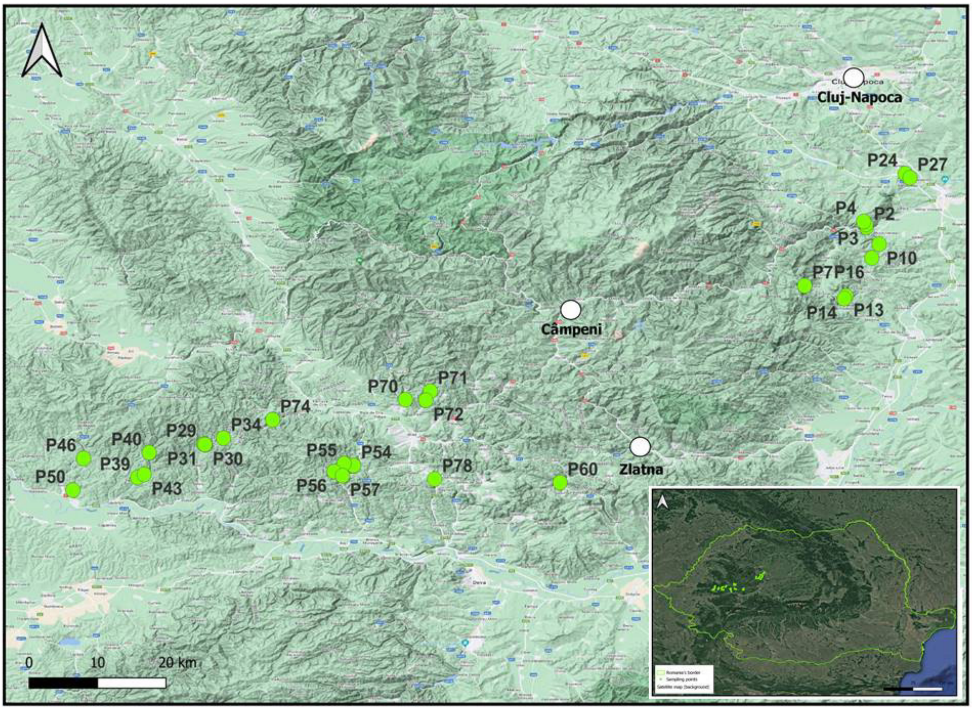



**Fig. 1**. *Geographical distribution of the sampling points*

Table 1 lists the sampling points, including their coordinates, the water source type (spring, stream, or well), and the measured pH.

**Table 1.** *Distribution and features of the sampling points.*

| Sample ID | Site | Type | pH | Coordinates | |
|---|---|---|---|---|---|
| | | | | ***N*** | ***E*** |
| P1 | Spring near road to Buru | spring | 7.31 | 46.51614 | 23.59192 |
| P2 | The lower waterfalls | stream | 8.33 | 46.50842 | 23.64048 |
| P3 | Middle Borzești Gorge | stream | 8.40 | 46.51356 | 23.63948 |
| P4 | The upper waterfalls | stream | 8.14 | 46.51871 | 23.63517 |
| P5 | Spring in centre Rimetea | spring | 7.43 | 46.45319 | 23.56738 |
| P6 | Well in the centre of Izvoarele village | well | 7.08 | 46.40006 | 23.54016 |
| P7 | Point upstream basins (Izvoarele village) | stream | 8.21 | 46.40272 | 23.52422 |
| P8 | Spring near road Sălciua | spring | 7.33 | 46.45518 | 23.46761 |
| P9 | Șipote waterfalls | waterfall | 7.77 | 46.40571 | 23.45998 |
| P10 | Upstream Moldovenești | stream | 8.23 | 46.478016 | 23.664321 |

| Sample ID | Site | Type | pH | Coordinates | |
|---|---|---|---|---|---|
| | | | | ***N*** | ***E*** |
| P11 | Big spring to Găvane | spring | 7.83 | 46.37378215 | 23.60265164 |
| P12 | Small spring to Găvane | spring | 7.80 | 46.37378225 | 23.60266812 |
| P13 | Stream after pine section | stream | 8.50 | 46.3842286 | 23.6021629 |
| P14 | At Gavane | stream | 8.51 | 46.37943 | 23.598975 |
| P15 | Spring in Podeni | spring | 7.47 | 46.43079 | 23.63027 |
| P16 | Stream between Podeni and Pietroasa | stream | 8.02 | 46.452699 | 23.650518 |
| P17 | Spring between Pietroasa and Moldovenesti | spring | 7.58 | 46.477684 | 23.66272 |
| P18 | Hășdate stream Cheile Turzii 1 | stream | 7.8 | 46.56505778 | 23.6768071 |
| P19 | Hășdate Stream Cheile Turzii 2 | stream | 7.82 | 46.5643716 | 23.6842254 |
| P20 | Hășdate affluent (left) | stream | 7.89 | 46.56232521 | 23.69103606 |
| P21 | Affluent Racilor stream | stream | 7.24 | 46.60997647 | 23.70441082 |
| P22 | SpringTureni | spring | 6.7 | 46.61597606 | 23.70649234 |
| P23 | Spring Cheile Turenilor | spring | 6.96 | 46.60591395 | 23.71153263 |
| P24 | Racilor stream | stream | 8.08 | 46.60547319 | 23.71282127 |
| P25 | Shallow spring | spring | 7.37 | 46.60064863 | 23.71702568 |
| P26 | Affluent Racilor stream (right) | stream | 7.65 | 46.5969597 | 23.7191388 |
| P27 | Affluent Racilor stream (stone quarry) | stream | 8.12 | 46.5978715 | 23.7221041 |
| P28 | Spring Roșia Nouă | spring | 7.31 | 46.1166526 | 22.3980453 |
| P29 | Stream after spring (P28) | stream | 8.56 | 46.1165346 | 22.3987048 |
| P30 | Pond Roșia Nouă | pond | 8.24 | 46.1152165 | 22.4011229 |
| P31 | Petriș stream in Roșia Nouă | stream | 8.46 | 46.1156634 | 22.4006482 |
| P32 | Well Roșia Nouă | well | 7.42 | 46.1167275 | 22.4021612 |
| P33 | Petriș stream downstream Obârsia | stream | 7.76 | 46.1274422 | 22.4349795 |
| P34 | Affluent Petriș stream | stream | 8.55 | 46.127221 | 22.4352019 |
| P35 | Roșia Noua spring | spring | 6.83 | 46.11386988 | 22.40136358 |
| P36 | Well in Corbești | well | 7.10 | 46.0866038 | 22.3888061 |
| P37 | Affluent Petriș stream (Corbești) | stream | 7.55 | 46.078117 | 22.384998 |
| P38 | Petriș stream | stream | 7.65 | 46.0493681 | 22.3882655 |
| P39 | Spring in Temeșești | spring | 8.10 | 46.0560954 | 22.2742753 |
| P40 | Upstream Troas affluent | stream | 8.3 | 46.1009959 | 22.2962234 |
| P41 | Troaș stream | stream | 7.62 | 46.1013846 | 22.2961787 |
| P42 | Troaș affluent downstream | stream | 7.60 | 46.0805159 | 22.3003221 |
| P43 | Troaș stream downstream Săvârșin | stream | 8.10 | 46.0615179 | 22.2868142 |
| P44 | Julița stream downstream Slatina de Mureș 1 | stream | 7.88 | 46.1560409 | 22.1825789 |
| P45 | Julița stream downstream Slatina de Mureș 2 | stream | 7.71 | 46.1308698 | 22.1751594 |
| P46 | Affluent Julița stream | stream | 8.24 | 46.090331 | 22.173169 |
| P47 | Spring downstream Julița | spring | 7.36 | 46.0653764 | 22.1451813 |
| P48 | Well in Julița | well | 6.9 | 46.0545446 | 22.133562 |

| Sample ID | Site | Type | pH | Coordinates | |
|---|---|---|---|---|---|
| | | | | *N* | *E* |
| P49 | Bălcescu stream | stream | 7.67 | 46.035404 | 22.106122 |
| P50 | Stejar stream | stream | 8.06 | 46.033025 | 22.153194 |
| P51 | Cerbia stream | stream | 7.05 | 46.0385959 | 22.4476029 |
| P52 | Spring | spring | 6.82 | 46.0379853 | 22.4479596 |
| P53 | Spring on the roadside | spring | 7.23 | 46.0743243 | 22.6765123 |
| P54 | Șarpe stream | stream | 8.66 | 46.07753423 | 22.67930534 |
| P55 | Sârbi stream | stream | 8.73 | 46.081039 | 22.661577 |
| P56 | Sârbi stream downstream Valea Poienii | stream | 8.68 | 46.066849 | 22.642652 |
| P57 | Vișa spring | spring | 8.36 | 46.05927768 | 22.65841995 |
| P58 | Sârbi stream upstream of Vorța | stream | 7.86 | 46.030896 | 22.667898 |
| P59 | Sârbi stream in Valea Lungă | stream | 7.83 | 45.984276 | 22.683951 |
| P60 | Geoagiu stream downstream Almașu | stream | 8.52 | 46.04686 | 23.066191 |
| P61 | Spring in the forest | spring | 7.53 | 46.046919 | 23.064608 |
| P62 | Voia downstream spring | spring | 7.72 | 46.040195 | 23.055581 |
| P63 | Spring in Voia | spring | 7.42 | 46.035768 | 23.04588 |
| P64 | Almășel stream | stream | 7.32 | 46.0535626 | 23.0760686 |
| P65 | Bălașa stream | stream | 7.56 | 46.0790215 | 23.0666046 |
| P66 | Ribișoara spring 1 | spring | 7.46 | 46.041913 | 23.072566 |
| P67 | Ribișoara spring 2 | spring | 7.07 | 46.1998411 | 22.7758753 |
| P68 | Well in Ribișoara | well | 7.10 | 46.2164464 | 22.7745376 |
| P69 | Ribița stream base of the gorge | stream | 7.55 | 46.228845 | 22.770022 |
| P70 | Ribița stream | stream | 8.41 | 46.1966692 | 22.776397 |
| P71 | Junc stream downstream Dumbrava | stream | 8.09 | 46.212113 | 22.823147 |
| P72 | Junc stream downstream Crișan | stream | 8.45 | 46.195795 | 22.814543 |
| P73 | Vața stream upstream | stream | 7.62 | 46.128577 | 22.507714 |
| P74 | Vața stream downstream | stream | 8.49 | 46.1603619 | 22.5276124 |
| P75 | Spring in Căzănești | spring | 7.60 | 46.1631897 | 22.5339477 |
| P76 | Luncoiu stream | stream | 7.61 | 46.068456 | 22.7903386 |
| P77 | Vălișoara spring | spring | 7.25 | 46.0531961 | 22.830805 |
| P78 | Căian stream downstream Vălișoara | stream | 8.07 | 46.0531348 | 22.8310603 |

## MATERIALS AND METHODS

The background information was obtained from the literature and from the available geological and hydrogeological maps. These data were used to produce the workplan and to establish the potential transects. The transects were outlined by using specific software as Quantum GIS and

Google Earth. The field investigations consisted of four campaigns that mainly targeted the ophiolitic areas defined in the background analysis stage. The north-eastern zone was investigated during three field campaigns focusing on the areas Hășdate-Tureni, Bedeleu, and Trascău. The southern zone was investigated during one campaign, that targeted the whole ophiolitic region located north of the Mureș valley. Field campaigns were carried out during the period 31.10.2022 – 14.05.2023.

During the field stage, the transects were tracked, and in-situ measurements of the collected water samples were carried out using the multiparameter portable meter WTW 350i. The following parameters were measured in-situ: temperature, pH, redox potential and electrical-conductivity; the salinity and TDS were derived from the latter. Water samples were taken from selected points of interest in order to carry out further analyses in the laboratory. Geographical coordinates were recorded for each sampling point. The Geo Tracker application was used to mark sampling points and other field data. In the final stage, the obtained data were systematized and interpreted in order to obtain an overview of the alkaline waters' distribution in the study area.

## RESULTS AND DISCUSSIONS

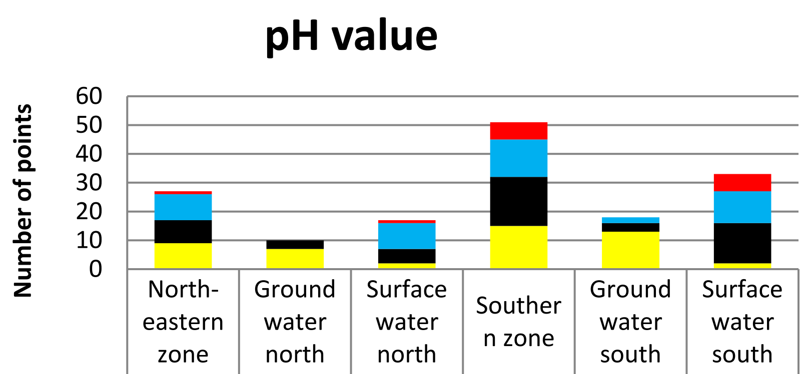
The total number of points investigated in this study is 78. All types of water sources that could have an alkaline character, or can provide information on the genesis and distribution of alkaline waters were considered. Depending on the source type, the sampling points consist of 5 wells, 23 springs and 50 collection points are represented by surface running waters (streams).

The electrical conductivity of the water samples is generally low, varying in the range of 119 to 631 μS/cm, and reflecting the low dissolved solids content. The temperature of the springs and wells is relatively constant, being around 10°C in the case of springs, and around 12°C for dug wells. Of course, the temperature was variable in the case of surface waters, fluctuating between 2.8°C and 15.1°C, in accordance with the air temperature.

The pH was measured in all the 78 investigated points, out of which the pH exceeded the value of 8.5 in 7 points, all of them representing groundwater, it was in the range of 8.0 to 8.5 in 22 points (2 groundwater and 20 surface water), between 7.5 and 8.0 in 25 points (5 groundwater and 20 surface water), and below 7.5 in 24 points (20 groundwater and 4 surface water). Figure 2 shows the statistical distribution of the measured pH values for the investigated water sources.

The spatial distribution of the sampling points in relation with the geological background is represented in figures 3 and 4. As shown in figure 3 and 4, the distribution of points where waters with high pH were measured, extends over the ophiolitic complex. The hypothesis of the current research, inferring that the ophiolitic areas are potential generators of alkaline waters, was confirmed. The number of springs that were identified in the ophiolitic areas is low, as these rocks exhibit low permeability, and therefore, scarce conditions for the accumulation of groundwater. However, in the north-eastern zone, the ophiolites are in contact with Jurassic limestones, that are able to accumulate important amounts of water. Additionally, the limestones are prone to yield neutral-alkaline waters, usually with pH in the range 7.0 to 8.0.

Values of the pH above 8.5 were measured in 7 locations, all of them corresponding to surface running water. Their parameters measured in the field are presented in Table 2. The pH values measured in running waters in the ophiolitic areas allow us to presume that groundwater in the same areas would be even more alkaline.




| | North-eastern zone | Ground water north | Surface water north | Southern zone | Ground water south | Surface water south |
|---|---|---|---|---|---|---|
| above 8.5 | 1 | 0 | 1 | 6 | 0 | 6 |
| between 8 - 8.5 | 9 | 0 | 9 | 13 | 2 | 11 |
| between 7.5 - 8 | 8 | 3 | 5 | 17 | 3 | 14 |
| below 7.5 | 9 | 7 | 2 | 15 | 13 | 2 |

**Fig. 2**. *Statistical distribution of the measured pH values.*

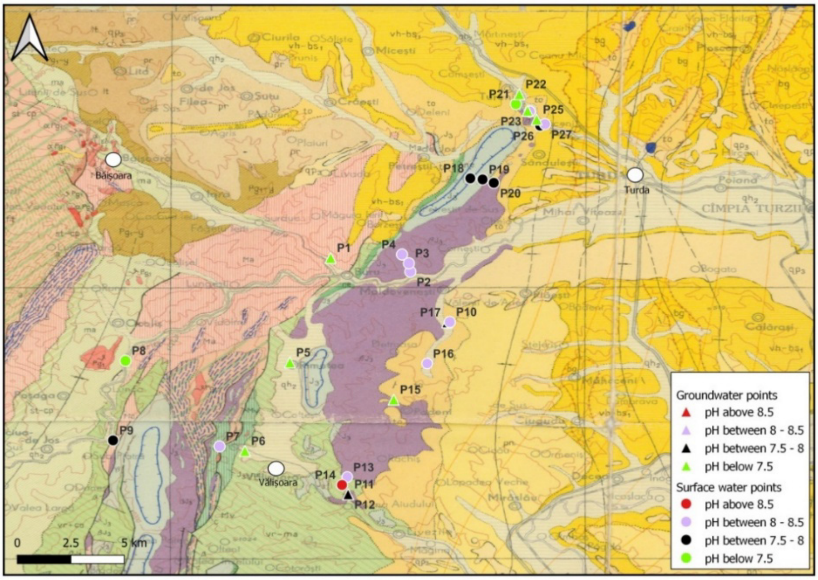



**Fig. 3**. *The pH values of the investigated water sources in the southern zone. The ophiolitic complex in magenta on the geological map. Background: The geological map of Romania 1: 200,000 (Geological Institute, 1967)*

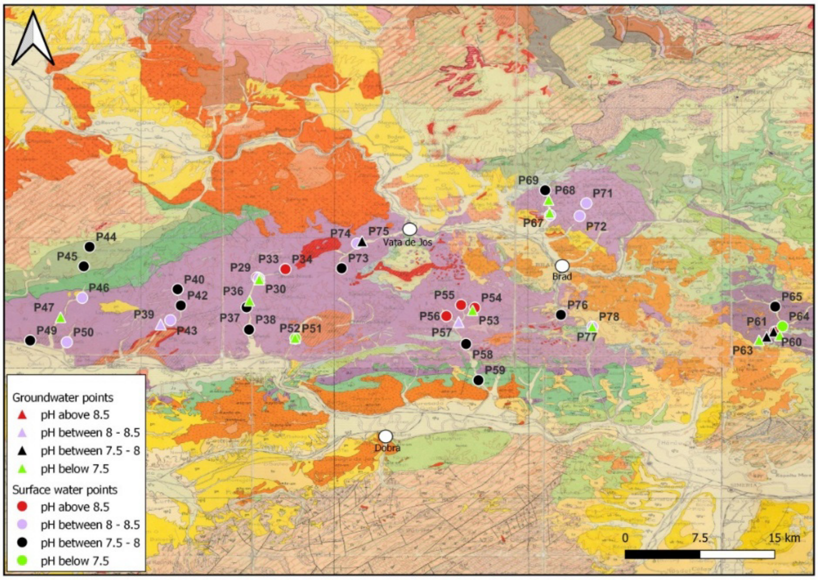



**Fig. 4**. *The pH values of the investigated water sources in the north-eastern zone. The ophiolitic complex in magenta, and Jurassic limestones in light blue on the geological map. Background: The geological map of Romania 1: 200,000 (Geological Institute, 1967)*

**Table 2**. *Physico-chemical in-situ measurement results for the most alkaline water sources*

| Sample ID | Site | pH | Tempera-ture | Salinity | Conducti-vity | TDS | Redox potential |
|---|---|---|---|---|---|---|---|
| | | | (°C) | (‰) | µS/cm) | (mg/l) | (mV) |
| P14 | At Gavane | 8.51 | 3 | 0.1 | 314 | 200 | -77.6 |
| P29 | Stream after spring (P28) | 8.56 | 12.7 | 0.1 | 412 | 261 | -83.3 |
| P34 | Affluent Petriș stream | 8.55 | 11.7 | 0 | 293 | 187 | -83.1 |
| P54 | Șarpe stream | 8.66 | 11.8 | 0.1 | 299 | 192 | -90 |
| P55 | Sârbi stream | 8.73 | 14.1 | 0 | 278 | 177 | -95.6 |
| P56 | Sârbi stream downstream Valea Poienii | 8.68 | 13.3 | 0 | 266 | 172 | -91.1 |
| P60 | Geoagiu stream downstream Almașu | 8.52 | 12.1 | 0.1 | 312 | 201 | -81.6 |

We include here a brief description of the water points where pH values above 8.5 were measured. Point P14 is located north of Poiana Aiudului. The water sample was collected from the stream that flows towards the locality, a stream that crosses an area with limestones and ophiolites. This is the only point in the north-eastern zone of the study area that shows a pH above 8.5. In the southern zone, a first point identified and placed in this category is P29. This point is located in the Roșia Nouă area on a tributary stream of the Petriș stream. The geological substrate is ophiolitic, but the springs and wells in the area do not have a pH above 8. It is noteworthy that the water sample taken from the Petriș stream (P31) had a pH of 8.46. Also in the same area, on a left tributary of the Petriș stream located between the Roșia Nouă and Obârsia, point P34 was sampled, with a pH of 8.55. Also, in the southern part of the study area within the Metaliferi Mountains near the village of Vișca, 3 points with alkaline waters were found, identified as P54, P55 and P56. All these samples were taken from streams that cross areas with ophiolitic substrate. This group of points had the highest pH values in the entire study. They are located on different streams, and are not influenced by each other. Similar to the situation previously presented on the parallel valley from Roșia Nouă, waters with a higher pH are found in running water bodies and not in springs. However, it is worth noting that the most alkaline spring identified in the current research was measured in the town of Vișca (P57; pH=8.36).

A general remark on all points with high alkalinity concerns the low electric conductivity (266 – 412 μS/cm) and implicitly low TDS (172 – 261 mg/l). A general characteristic observed in the studied area is the compact texture of the rocks and the lack of deep fissures or fractures that would allow the circulation of fluids.

## CONCLUSIONS

The data obtained in the present research confirm the potential of the Apuseni Mountains to generate alkaline waters, related to the ophiolitic substrate. About 30 points with waters with pH above 8 were identified in the field. Most points with alkaline waters were sampled in streams that flow through areas with basic rocks. Generally, ophiolitic areas generated waters with a higher pH than areas with a mix of limestone and ophiolite. The measured values of the pH in streams decrease when crossing lower areas, mainly consisting of detrital sedimentary rocks. The pH of waters from wells is around 7, they are dug in low areas with Quaternary alluvium, and likely do not interfere with the bedrock, mostly consisting of compact ophiolitic rocks.

The compact structure of the bedrock does not favour the accumulation of groundwater, thus the number of springs in the area is very limited. The pH of the identified springs is below 8.0. Very likely, the pathway of groundwater that generates the tested springs is shallow, being confined to the superficial deposits, without intercepting the ophiolites. No hyperalkaline waters (with pH above 9.0) have been identified until now in the Southern Apuseni Mountains. As the ultramafic rocks are only locally developed, detailed investigations in the target areas could identify also this kind of waters.

The contacts between the ophiolitic rocks and limestones could provide more favourable environments for the accumulation of alkaline groundwater. By continuing this research, other areas with alkaline water potential can be identified and more information can be provided about the areas preliminary investigated in the current study (identification of additional sources, detailed characterization of the chemical composition).

Following these preliminary investigations, it can be stated that the study area has the capacity to generate alkaline waters, potentially with economic value. The areas with higher potential seem to be the north-eastern zone (Tureni – Buru – Trascău – Poiana Aiudului), and in the southern zone, Roșia Nouă – Vișca area. A detailed hydrogeological characterization of these areas may reveal exploitable alkaline water resources.

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