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PRELIMINARY CONSIDERATIONS REGARDING THE GEOTHERMAL POTENTIAL IN THE APUSENI MOUNTAINS AREA

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ABSTRACT. The Apuseni Mountains have a particular geological structure which gives distinctive geothermal features. They are located between the well-developed geothermal zone of the Pannonian Basin, and the Transylvanian Basin, which is a cold zone. Little information is available in the literature about the geothermal systems from this region. The synthesis of the literature data, combined with our field measurements show there is significant geothermal potential in the area. The thermal water sources are located along a NW-SE alignment. During the field campaigns, the flow rates and temperatures of the water sources were measured. A total flow rate of about 33 l/s was calculated for the study area at an average temperature of about 34 °C. The total thermal energy released by these sources by comparison to the common groundwater is more than 100,000 GJ/year. This geothermal potential could be used as sustainable energy sources for different activities, as agriculture (fish farming, greenhouses), heating (residential and administrative buildings), tourism and balneotherapy.

Key words: *thermal water, geothermal potential, Apuseni Mountains, renewable resources.*

INTRODUCTION

Located between an important geothermal area of Europe (the Pannonian Basin), and a cold structural unit (the Transylvanian Basin), the Apuseni Mts. show distinctive features from the geothermal point of view. Water sources with temperatures between 20 °C and 30 °C in most of the cases, are located on an approximate NW – SE lineament from Beius Depression to the Mures couloir. Although these temperatures are characteristic for the lowest part of the geothermal domain, they reveal a non-negligible heat flux. In the Romanian regulations, as well as in most of the international classifications, geothermal waters are defined as having source temperatures higher than 20 °C (Order No. 87/2008). Some of the investigated waters, although not reaching the 20 °C threshold, show higher temperatures than common groundwater in the study area. We conventionally considered 10 °C as the baseline temperature for groundwater in the investigated area. Although not geothermal waters sensu stricto, the waters with temperatures between 10 °C and 20 °C show geothermal influences (Orășeanu, 2016), and were also subject to our investigation.

There is a long history of using the thermal waters in the area for therapeutic or recreational purposes, the thermae from Calan (Ad Aquas) and Geoagiu Băi (Germisara) being known since the Roman times (Țentea, 2015; Pricăjan and Airinei, 1981). Currently, there are relatively few studies available explaining the occurrence of these waters and the geothermal potential in the area. An important source of information is the catalogue of the mineral water sources from Romania compiled by the Institute of Balneology and Physiotherapy that includes accurate physical and chemical parameters of the waters (IBF, 1961-1973).

Some other general works area dealing with the geothermal resources of Romania, including the Apuseni Mts. area (e.g. Pricăjan, 1972; Pricăjan and Airinei 1981; Gheorghe and Crăciun, 1993). A more recent synthesis on the karst hydrogeology from the Apuseni Mts. (Orășeanu, 2016) contains relevant information regarding the features of the main geothermal The most eloquent is the work “Hidrogeologia Carstului din Munții Apuseni” which makes some references to the emergence of geothermal waters in this area. The main geothermal areas noted are: Beiuș Basin, Moneasa area, Rapolt Crystalline Island and Geoagiu Băi.

To the west of the Apuseni Mountains, the Pannonian Basin is a renowned area for its geothermal resources. The geothermal and geochemical features of this basin have been discussed in numerous papers (e.g. Kazmer, 1990; Varsanyi et al., 1997). The Romanian side of the Pannonian Basin corresponds to the Western Plain. This unit also hosts geothermal resources, the water temperature often exceeding 50 °C (e.g. Țenu et al., 1981; Roba, 2010).

The use of geothermal resources is reducing the consumption of fossil fuels, thus contributing to the decrease of the environmental footprint of the human activities. At the national and international level, geothermal energy is considered as a renewable energy source, its use being suitable in the domestic or even industrial systems (Cirstea et al., 2019; Colesca and Ciocoiu, 2013). Worldwide there are numerous examples of such practices in agriculture, energy production, industry, home heating etc. (e.g. Lashen, 1988).

STUDY AREA

From a geological and morphological point of view, the sampling points are located in different structural units (Metaliferi Mountains, Codru Moma Mountains, Cerna-Strei Depression, Brad Depression, Vad – Borod Depression, Beiuș Depression, Sebișului Depression and the Western Hills). The sampling points are distributed along the marginal area of the Apuseni Mountains and in the neighbouring depressions. This distribution is shown in figure 1.

All sampling points included in the present study are listed in table 1. A total of 40 water sources (springs and wells) have been sampled, following an alignment that crosses the Apuseni Mountains from NW to SE. The highest number of sampling points are concentrated in Moneasa area (MA 19, MA 20, MA 21, MA 22, MA 23, MA 24, MA 25, MA 39) Geoagiu area ”Rapolt crystalline island” (MA 3, MA 4, MA 5, MA 6, MA 7, MA 8, MA 9, MA 10, MA 11, MA 12, MA 13, MA 14, MA 15, MA 16, MA 38, MA 41) and the northern part of the Beiuș Depression (MA 26, MA 27, MA 28, MA 29, MA 30, MA 31, MA 32, MA 33, MA 34, MA 40).

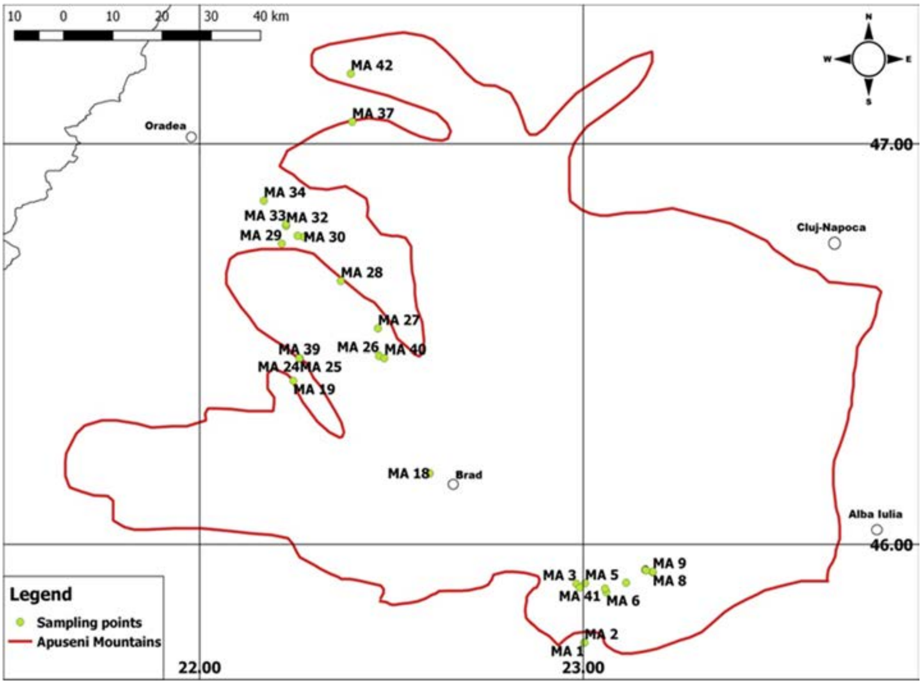

Fig. 1. *Geothermal water sampling points.*

Table 1. *Sampling points from the study area*

Sample ID	Site	Coordinates		Sample ID	Site	Coordinates	
		N	E			N	E
MA 1	Calan bai romane	45.754008	23.002722	MA 21	Moneasa 2	46.465350	22.260560
MA 2	Calan izvor	45.754083	23.003277	MA 22	Moneasa 3	46.465350	22.260560
MA 3	Chimindia foraj	45.901611	22.981888	MA 23	Moneasa 4	46.465350	22.260560
MA 4	Chimindia fantana	45.893527	22.983916	MA 24	Moneasa 5	46.465350	22.260560
MA 5	Banpotoc	45.902611	23.004611	MA 25	Moneasa 6	46.464994	22.260939
MA 6	Rapoltel	45.880250	23.060027	MA 26	Vascau	46.470920	22.467360
MA 7	Rovina	45.889000	23.056694	MA 27	Stei (Liceu)	46.538260	22.464880
MA 8	Nătău	45.930250	23.181250	MA 28	Beius foraj 3001	46.657147	22.368027
MA 9	Nătău	45.931500	23.181194	MA 29	Rabagani strand	46.750120	22.213980

MA 10	Geoagiu izvor 1	45.937166	23.162083	MA 30	Cosdeni cismea	46.767161	22.270719
MA 11	Geoagiu foraj 9	45.936638	23.162083	MA 31	Albesti	46.769990	22.255220
MA 12	Geoagiu foraj 6	45.936416	23.161250	MA 32	Rotaresti cismea	46.794690	22.225380
MA 13	Geoagiu Bai Romane	45.935527	23.161861	MA 33	Rotaresti cazan	46.799540	22.225210
MA 14	Geoagiu supraplin	45.936138	23.161250	MA 34	Ceica	46.857660	22.167220
MA 15	Geoagiu Rozalia	45.936027	23.161000	MA 37	Alesd foraj	47.055180	22.397750
MA 16	Geoagiu foraj 3	45.934527	23.163861	MA 38	La Feredee	45.903788	23.111844
MA 17	Vata Bai 1	46.177480	22.599480	MA 39	Grota Ursului	46.465827	22.259688
MA 18	Vata Bai 2	46.177480	22.599480	MA 40	Vascau Lenin	46.465344	22.481379
MA 19	Dezna	46.408933	22.244202	MA 41	Chimindia ferma	45.891786	22.991069
MA 20	Moneasa 1	46.465350	22.260560	MA 42	Padurea Neagra	47.175319	22.393916

The geological substrate and structural conditions vary for the different sampling points. In this regard, MA 1, MA 2, MA 17 and MA 18 are located on thick Quaternary alluvial deposits.

Points MA 3 to MA 16, MA 38 and MA 41 are located on the border of the Metaliferi Mountains. The area where these points are located has geological characteristics more distinct from the usual ones in the south of the Southern Apuseni Mountains. In the specialized literature it is known as the Crystalline “island” of Rapolt (Ianovici et al., 1976). At depth, a carbonate complex is well represented, and includes stratified and massive limestone, dolomitic limestone, ankerite, and stratified dolomite (Orășeanu, 2016). The points MA 19 to MA 25 and MA 39 are located in the marginal area of the Codru Moma Mountains. Magmatic rocks as rhyolites occur in the substrate, together with a wide variety of limestones: pink and red limestone, massive and stratified reef limestone, black limestone with sandstone interlayers and massive white limestone containing bauxite intercalations (Ianovici et al., 1976).

The points MA 26 to MA 34 extend from south to north on the Depression of Beiuș and reach the eastern margin of the Pannonian Basin. This area includes Neogene sedimentary rocks in the substrate (clays, sands, gravels, limestone). Point MA 37 is in the Vad-Borod Depression, with geological characteristics resembling the Beiuș Depression.

MATERIALS AND METHODS

The main water sources with geothermal characteristics have been identified using the published data (Orășeanu, 2016; Pricăjan and Airinei, 1981) etc. The data available for these points were analysed and converted to create a homogeneous database. Subsequently, the points were visualised and analysed by using specific software (Quantum GIS, Microsoft Excel). Water flow and temperatures were measured in the field in 36 points. The water temperature was measured by using a WTW 350i multimeter, while the flow rates were determined by using calibrated vessels, and simultaneously measuring the time. The flow rate was established using the formula: $Q = \Delta V / \Delta t$ (Q-flow; ΔV-volume in liters; Δt-time in seconds).

RESULTS AND DISCUSSIONS

In the context of sustainable development, geothermal energy is regarded as a renewable and environmental friendly energy source. For many areas of the globe, geothermal energy is an important source of energy. However, in the Romanian case, the geothermal resources are not considered a major source of energy.

The potential of geothermal energy in Romania is estimated at 7 × 106 GJ (Colesca and Ciocoiu, 2013). Compared to other renewable energy sources (wind energy, hydroelectric energy) geothermal is considered a rather minor resource, not suitable for producing electricity, due to its low enthalpy. Although, the recent technological developments in thermal energy recovery and use, may increase the interest for this resource.

Table 2. *Geothermal energy in direct use (Source Colesca and Ciocoiu, 2013)*

Field of use	%
Bathing and swimming	42.21%
District heating	38.47%
Individual space heating	8.67%
Geothermal heat pumps	3.59%
Fish farming	2.94%
Greenhouse heating	2.73%
Agricultural drying	0.91%
Industrial process heat	0.49%

Table 2 shows that in Romania the highest amount of geothermal energy is used for recreational purposes in spas and health centres. This type of use is also common in our study area at Călan, Geoagiu-Băi, Moneasa, Felix and Aleșd. This type of use is considered sustainable and has perspectives for development through European Union funding (Surdu et al., 2015). Another significant amount is used for heating the private houses/common spaces with this type of heating agent. The most eloquent example in the area of the Apuseni Mountains is the town of Beiuș, which withdraws the thermal energy needed to heat the homes and public buildings from the thermal aquifer. A low percentage of geothermal energy is used in the primary industrial sector (fish farming, greenhouses), and a similar low percentage is present in the secondary industrial sector (heat for industrial processes).

Table 3. *Geothermal power generation in Romania, Source: (IGA, 2019)*

	Energy	Energy	Energy	Energy	Energy
	TJ/year	TJ/year	TJ/year	TJ/year	TJ/year
Year	1995	2000	2005	2010	2015
Romania	2.753	2.871	2.841	1.265,4	1.905,3

Statistical data presented in table 3 show a significant increase in the use of geothermal energy, especially between 2010 and 2015 (IGA, 2019). Relevant data regarding the confirmed and tested geothermal resources in the study area were compiled (Pricăjan, 1972; Pricăjan and Airinei, 1981; Orășeanu, 2016; IBF, 1961-1973). A number of 32 thermal groundwater sources including several high-yield drilled wells, give a total flow rate of about 398 l/s at a temperature of 27.97 °C (weighted arithmetic mean). During the field campaigns we identified 40 points with thermal water, and flow rate was measured for most of them (Table 4).

Table 4. *Geothermal waters with measured temperature and flow*

Sample ID	Site	Temp. (°C)	Flow (l/s)	Sample ID	Site	Temp. (°C)	Flow (l/s)
MA 5	Banpotoc	20.6	0.66	MA 28	Beius foraj 3001	79.8	4.41
MA 6	Rapoltel	23.3	1.77	MA 29	Rabagani strand	23.6	0.87
MA 7	Rovina	21	0.05	MA 37	Alesd foraj	39.6	4
MA 10	Geoagiu izvor 1	28	0.07	MA 38	La Feredee	20.1	0.04
MA 11	Geoagiu foraj 9	28.3	1.09	MA 3	Chimindia foraj	16.0	0.24
MA 12	Geoagiu foraj 6	27.4	0.23	MA 17	Vata Bai 1	10.9	0.15
MA 14	Geoagiu supraplin	31.8	1.53	MA 26	Vascau	11.1	0.66
MA 15	Geoagiu Rozalia	27.5	1	MA 30	Cosdeni cismea	16.5	0.08
MA 16	Geoagiu foraj 3	28.9	2.98	MA 31	Albesti	17.8	0.26
MA 18	Vata Bai 2	32.7	0.4	MA 32	Rotaresti cismea	15.9	0.11
MA 19	Dezna	32.6	0.64	MA 33	Rotaresti cazan	14.6	0.14
MA 20	Moneasa 1	22.8	2.46	MA 34	Ceica	18.5	0.19
MA 21	Moneasa 2	26.3	5.72	MA 40	Vascau Lenin	11.4	0.23
MA 22	Moneasa 3	24.7	0.16	MA 41	Chimindia ferma	14.5	0.81
MA 23	Moneasa 4	25.2	0.38	MA 42	Padurea Neagra	11.2	0.03
MA 25	Moneasa 6	23.8	1.61				

The examination of data shows a relative homogeneity in terms of temperature. Flows are influenced by the type of exploitation, often the drilled wells having higher flows than the springs. The depth of the drilling directly affects the water temperature. In this case the geothermal gradient should be considered and predictions on the temperature of the aquifers can be made. by using the weighted arithmetic mean for temperature, and summing all measured flows, a total flow rate of 32.97 l/s at average temperature of 34.05 °C was calculated. The thermal contribution from the geothermal resource was calculated as 24.05 °C by respect to the conventionally considered background temperature of groundwater in the area, of 10 °C. The heat input from these geothermal flows is approximately 792,928 calories/s. According to the previously calculated flow rate and geothermal contribution, the generated energy is about 3.31 MJ/s. Annually this energy reaches about 104 455 GJ/year, which is approximately 1.49% of Romania's estimated geothermal potential.

At local scale, a flow rate of 6.9 l/s at average 29.2 °C was calculated for Geoagiu area, totalizing an energy contribution from the geothermal source of about 17,344 GJ/year, while for Moneasa area the flow rate is 10.33 l/s at 25 °C, and the energy contribution is about 20,183 GJ/year.

Table 5. *Geothermal waters with unmeasured flow*

Sample ID	Site	Temp. (°C)
MA 1	Calan bai romane	22.9
MA 2	Calan izvor	28.7
MA 4	Chimindia fantana	14.7
MA 8	Nătău	20.2
MA 9	Nătău	15.9
MA 13	Geoagiu Bai Romane	16.1
MA 24	Moneasa 5	26
MA 27	Stei (Liceu)	44.5
MA 39	Grota Ursului	18.8

For the nine points listed in table 5 the flow measurement was not possible; the arithmetic mean of water temperature is 23.12 °C.

Some of the sources listed in tables 4 and 5 show temperatures between 10 and 20 °C, therefore they are not considered geothermal sources sensu stricto, but rather sources with geothermal influence. The amount of energy exceeding the background of groundwater in the area has also been considered. Additionally, these waters represent an indicator for water reservoirs with potentially higher temperature in the depth. These data highlight the diverse and increased potential of the area in terms of geothermal resources.

According to the data presented above, the investigated area of the Apuseni Mountains and the show medium geothermal potential. Although not suitable for the production of electricity, this geothermal potential can be used for other types of activities.

Good examples in the literature show that such sources are suitable for heating greenhouses with vegetables and flowers (Berdondini et al., 1995; Sordelli and Karkoulias, 1995). The lower temperature geothermal fluxes are able to generate optimum temperature for vegetables, for example tomatoes and cucumbers have maximum growth efficiency at temperatures between 20-25 °C (Boyd and Lund, 2000). The thermal fluxes obtained from these sources can be used for processing food (drying) or preparing them for storage (Arason, 2003; Sordelli and Karkoulias, 1995).

Fish farming in geothermal areas is a common practice in several countries. It is well suited for species such as: bass, catfish, salmon, sturgeon, carp, shrimp, crayfish, crabs, oysters, clams, mussels (Boyd and Lund, 2000). In such farms a high growth rate is obtained by eliminating the periods of inactivity for the fish, determined by the cooling of the water. These fish farms can diversify the species grown due to the warm environment that allows the growth of allochthonous species.

Most of the practices and models presented above can be implemented for the Apuseni Mountains area. Considering the positioning of thermal sources in the low and flat areas (Brad Depression, Beius Depression, Cerna-Strei Depression) this energy can be used for greenhouses heating. Fish farms are another viable option for the use of geothermal energy in this area, traditional species such as carp and catfish are suitable for this type of farming.

The rich river network of this area allows the creation of facilities for fish farming that can use a mix between thermal and cold waters. This mix of waters can be adapted according to the requirements of the target species and the season. The use of these resources can create economic opportunities at local and regional level.

CONCLUSIONS

The geothermal water sources sampled within the current study follow an alignment that crosses the Apuseni Mountains from NW to SE. This alignment extends over the territory of three counties (Bihor, Arad and Hunedoara), offering development opportunities to the local administration and communities. Based on field measurements and bibliographic data, a quantitative estimation of the geothermal resources in this area was performed. Potential use of this resource for agriculture (aquaculture, greenhouses) and more extensive heating of residential and administrative buildings is proposed.

Use of these resources represents an economic opportunity for the disadvantaged communities from the area and at the same time an eco-friendly way for the food production. The current uses of thermal water (leisure, heating) can be extended in terms of number of beneficiaries and modern technologies should be implemented in order to increase its efficiency. For the future, this research aims to continue monitoring the area through qualitative and quantitative measurements of geothermal fluxes and creating the premises for investments in the exploitation of these resources.

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