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HYDROGEOTHERMAL MODEL OF THE LOCALITY PROEVCE, REPUBLIC OF NORTH MACEDONIA

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Abstract

The paper presents the results from the research on the "Proevce" hydrothermal system, which is located near Kumanovo. The terrain on which thermo-mineral waters occur is the left bank of the river terrace of the Kumanovska River, above which the hill Golem Rid rises steeply, composed of old Paleozoic marbles and schists.

The explorations showed that there are three significant springs with thermo-mineral water in the research area: artesian borehole labeled S-1, natural spring with catchment K-2 and spa spring. According to its chemical composition, the water is hydrocarbonate - sodium-potassium poorly magnesian.

According to the performed hydro-chemical and balneological tests and analyses, the water from this deposit meets all the requirements for using water for drinking and treatment.

Key words: *Proevce, thermo-mineral water, thermal spring, model, hydro-chemical properties*

INTRODUCTION

The research area, i.e., the locality village "Proevce" is part of the Kumanovo valley and is located about 4 km southeast of the city of Kumanovo (Fig.1). In fact, the research area is located on the outskirts of the city (at the exit to Kriva Palanka).

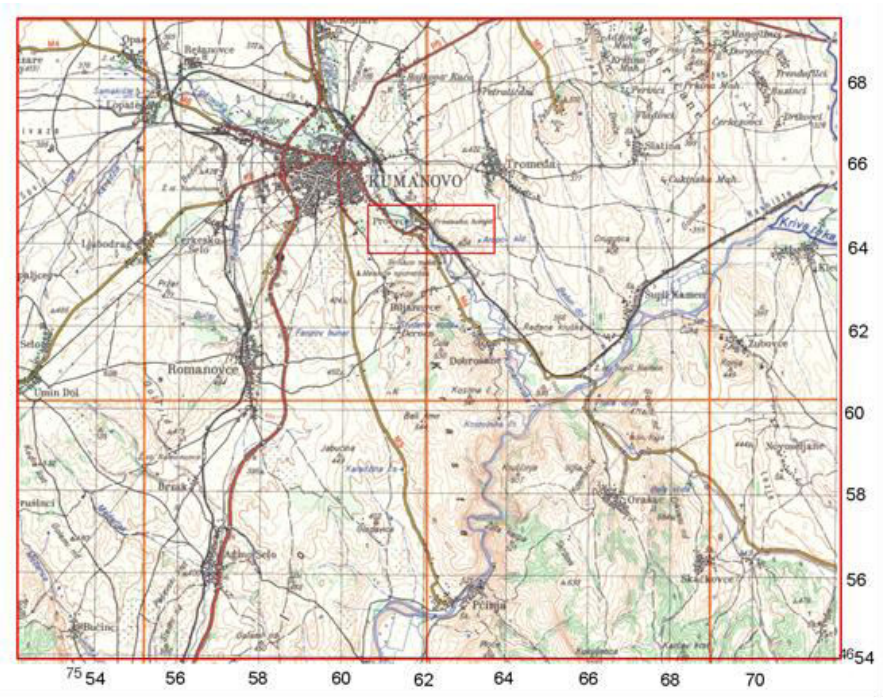


Figure 1. Geographical position of the researched area.

The hydrographic network in the Kumanovo region consists of the middle and lower flows of the rivers Pcinja, Kumanovska and Kriva Reka and some smaller watercourses that completely belong to the basin of the river Pcinja. Its tributaries are Kumanovska Pека, which is also the most important, Kriva Pека, Bistrica, Dragomanska Reka, Petroshnica and Luka. Torrential flows are registered towards the city and towards the villages Dobroshane and Banevi Trla, which are not regulated.

The main river that passes in close proximity to the village of Proevce is the Kumanovska Reka. It is a right tributary of the river Pcinja. Pcinja further flows into the Vardar river, which belongs to the Aegean Sea basin (Aegean basin area).

In the geological composition of the wider vicinity of the Proevce locality participate Paleozoic rocks (marbles, chloritic schists, sericitic and phyllitic schists, serpentinites), Jurassic rocks (flysch, limestones), Cretaceous rocks (granodiorites), Neogene sediments (sandstones, andesitic tuffs, sands and gravels, calcareous limestones) and Quaternary deposits (kyanite, proluvium, river terraces, deluvium and alluvium) [1].

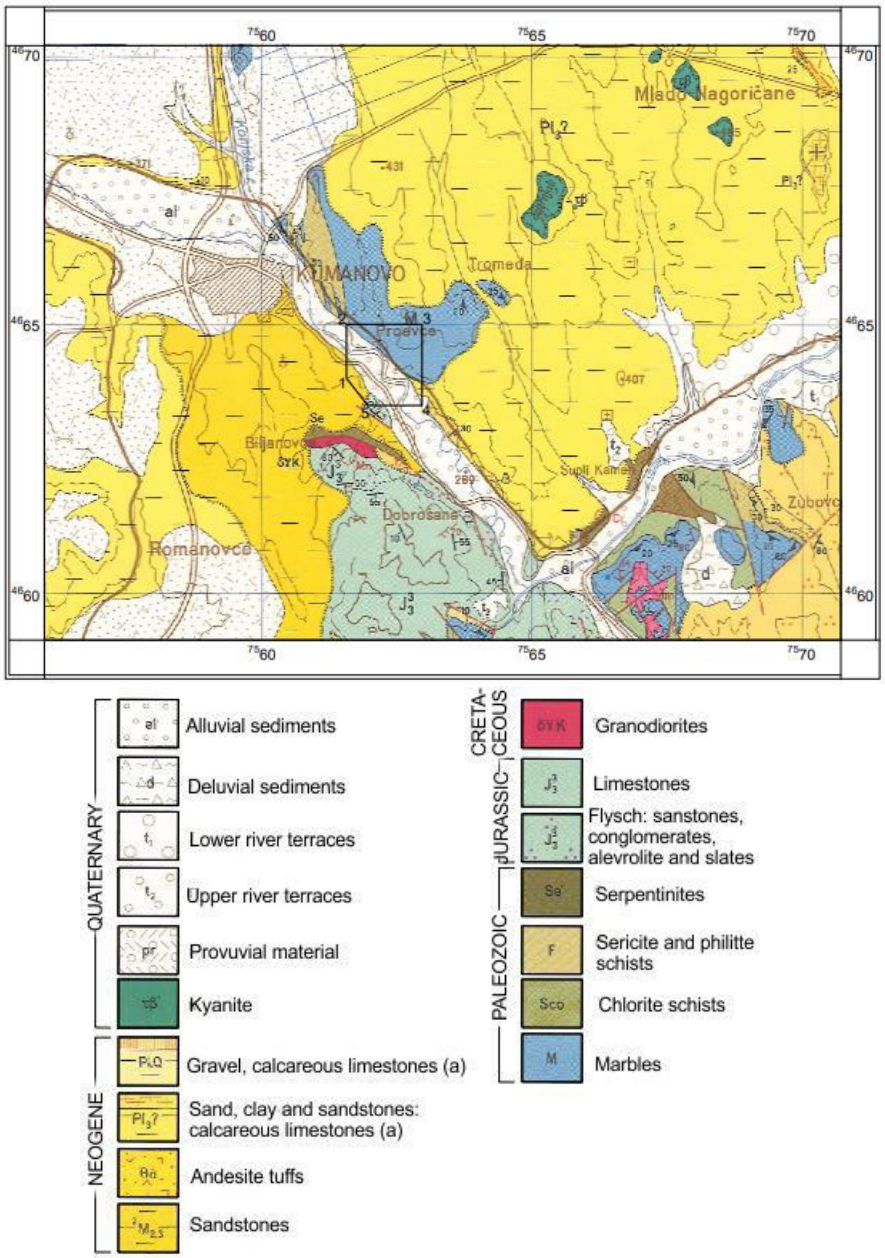


Figure 2. Geological map of the terrain

Hydrogeological research in the wider area of Kumanovo, and in connection with finding potential deposits of underground water suitable for turning into springs to meet the increased consumption of water in the city, was carried out by the Civil Engineering Institute "Macedonia" under the direction of I. Loncar, in the period 1991 - 93, in which the area of Proevce - Kumanovska spa is also treated.

Hydrogeological data for the Proevce - Kumanovska spa locality are also found in the research conducted by G. Kotevski (1967 and 1977).

In the period from 1952 - 1960, a significant amount of research work was carried out in the area of the spa, which is presented in the form of reports. Research during that period was carried out by Z. Kapetanovich (1961), A. Butakov (1952), B. Stepanovich (1952), M. Janjich (1952), P. Nikiforovich (1960).

The latest research on the "Proevce" area was carried out in 2022 by O. Spasovski and others, for the needs of preparation of an Elaborate.

MATERIAL AND METHODS

Hydrogeological regionalization of the terrain

For the analysis of the conditions in which the thermo-mineral springs appear and form, a hydrogeological mapping of the terrain was carried out. This mapping provides a basis for hydrogeological regionalization of the terrain and is a basis for building a geohydrothermal model of the deposit.

In the research area two basic classes of rock masses are present: water-permeable and water-impermeable. In the class of permeable rocks, there are defined rocks in which two basic types of wells have been formed:

- boundary type of wells, and
- karst water body.

Within the class of impermeable rocks, two groups are distinguished:

- mostly impermeable rocks with local fissure-type wells,
- hydrogeological insulators, practically without wells.

Thermo-mineral springs in the area of the village Proevce occur as a consequence of the overall geological - hydrogeological - tectonic conditions and events, not only in this locality, but also in the wider region. In an attempt to clarify and connect the various phenomena and manifestations with a hydrogeothermal character, an analysis of all known and mapped indications was performed: the geological - tectonic assembly, thermo-mineral springs, temperature anomalies of the waters and soil, the chemical composition of the waters and thermo-mineral changes.

The general degree of geo-thermality in the region should be related to the neotectonic activities within the Vardar zone and the formation of faulted structures followed by volcanic activity. In the area close to the Proevce region, in the terrains of the Kratovo - Zletovo region, volcanic activity in the Pliocene - Quaternary period is manifested by intrusions of young effusives and occurrences of thermal springs. The outflows of thermo-mineral water on the surface of the terrain are related to the determined regional fault and the numerous cracks in the marbles, which served as natural channels for the drainage of atmospheric and shallow underground water in the deeper parts.

The Proevce springs, which are now captured and occupied, occur primarily along a straight zone with a length of about 120 m and a width of 30 m, immediately between the railway line and the road [2].

All the Proevce springs actually represent discharges through open cracks and channels formed in the surface parts of the calcareous sediments, which are precipitated by the thermo-mineral waters that come under pressure from the deep zones in the marbles. During the long period of the welling out, new amounts of calcareous tuff are deposited, which closes individual channels, and the water expands and finds new paths through nearby cracks. This leads to the displacement of the sources but it remains a zone of "fractured headwater" in which these local displacements take place.

RESULTS AND DISCUSSION

Geothermomineral anomalous zone

The spring of thermo-mineral water in this locality was registered on the surface of the terrain at the places of the current springs. However, during the research, it was determined that the geothermal and mineral influences of the water extend over a much wider area than the places of these sources and the fault zone, which has been proven to be a supply channel for these waters.

With the field observations and measurements, various indicative factors were registered in the soil and waters, which indicate a wider zone of geothermomineral influences - anomalous zone. The most significant recorded are increased water temperatures, increased mineralization, presence of gases, appearance of travertine, hydro-chemical composition, etc. [3].

Water temperatures were measured in all open occurrences and catchments, exploration boreholes and wells, as well as along the course of the river. At the research site, the maximum water temperatures range from 27 - 31°C.

The mineralization of the waters in the deposit ranges within very wide limits, from M - 0,40 g/l to M - 2,5 g/l.

The occurrences of mineral waters in free wells, within the alluvial-terrace deposit, should be interpreted as part of the infiltrated thermo-mineral waters from the main spring zone, which spill out in the form of underground flows, mixing with the cold underground waters and thus forming new hydro-chemical and hydrogeological zone [4].

The presence of gases in the spring waters is evident and proven in terms of quality and quantity. It has been confirmed that all springs with thermo-mineral water contain 1,0 g/l.

With the tests, it was registered that separate underground waters from dug wells in the village Proevce have a pronounced mineral character and sour taste from the presence of CO_2.

Occurrences of travertine (scale) are indicators of the existence of thermo-mineral flows. They are registered on the surface of the terrain with a thickness greater than 4 m. All current sources at the ground surface have been shown to occur in the calcareous material.

Hydrogeochemical characteristics

Based on the chemical analyses of the characteristic water occurrences, the hydro-chemical type of the water was determined (Table 1). It can be seen from the analyses that all analyzed samples of thermo-mineral waters, according to the chemical type, are [5]:

- according to anions, they are hydrocarbonate
- according to cations, they are sodium-potassium-magnesium-calcium.

The three-component diagrams presented in Figures 3 and 4 show the anion-cation relations in some analyzed waters from the deposit in Kumanovska spa and its near surroundings.

Table 1. Chemical analyses of thermo-mineral waters from the immediate vicinity of the village Proevce

Place			A dug well next to the hotel	A spring above a pool	A dug well v. Proevce	Borehole Hunting home
ANIONS	HCO_3	mg/l	1178.80	1795.70	363.20	1432.40
		mil/Vol	19.3323	29.4495	5.9565	23.4914
	Cl	mg/l	196.50	196.50	33.10	196.80
		mil/Vol	5.5413	5.5403	0.9334	5.5498
	SO_4	mg/l	21.80	23.90	33.10	30.90
		mil/Vol	0.4539	0.4976	0.6891	0.6433
	ΣA	mg/l	1397.10	2016.10	429.40	1660.10
		mil/Vol	25.3275	35.4884	7.579	29.6845
CAT	Ca	mg/l	110.70	24.41	8.14	29.30
		mil/Vol	5.5239	1.2181	0.4062	1.4621
	Mg	mg/l	100.10	161.00	104.50	54.50
		mil/Vol	8.2282	13.2342	8.5899	4.4799

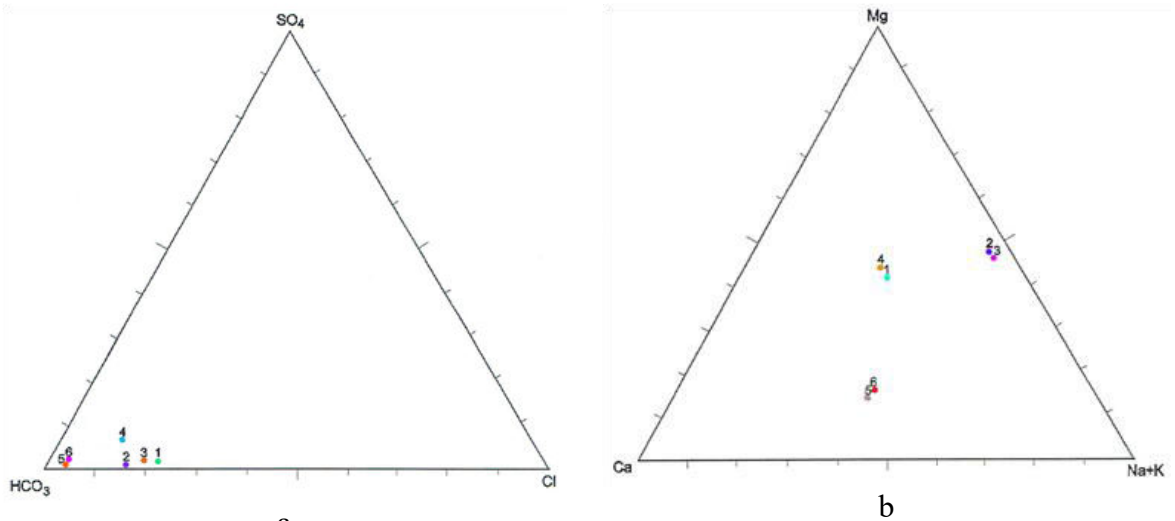
I O N S	Na+K	mg/l	124+19	286+31	195+28	40+18
		mil/Vol	143	317	223	58
		mil/Vol	5.8804	13.2346	9.11993	2.2008
	ΣK	mg/l	353.80	502.41	335.64	141.80
		mil/Vol	19.6325	27.6869	18.1954	8.1428
Mineralization (mg/l)			1750.90	2518.51	1995.74	1572.18

Table 2. Type of water calculated with Kurlov's formula

Place	Kurlov's formula	Type of water
A dug well next to the hotel	$M_{1,75}\frac{HCO_3-76;Cl-22;SO_4-2}{Mg-42;Na+K-30;Ca-28}$	Hydrocarbonate-magnesian, sodium-potassium-calcium
A spring above a pool	$M_{2,52}\frac{HCO_3-83;Cl-16;SO_4-1}{Mg-48;Na+K-48;Ca-4}$	Hydrocarbonate - sodium-potassium - magnesian
A dug well v. Proevce	$M_{1,99}\frac{HCO_3-79;Cl-19;SO_4-2}{Mg-47;Na+K-51;Ca-2}$	Hydrocarbonate, sodium-potassium - magnesian
Borehole Hunting home	$M_{0,57}\frac{HCO_3-79;Cl-12;SO_4-9}{Mg-55;Na+K-27;Ca-18}$	Hydrocarbonate - magnesium - sodium - potassium

The Na/K ratio in thermal water systems is usually in the range of 20:1 to 8:1. A lower value indicates higher temperatures. In our case, we have the following relations:

- A spring above a pool - Na/K = 286,0 : 31,0 = 9,22
- Main spring - Na/K = 287,0 : 28,0 = 13,22
- A dug well v. Proevce - Na/K = 195,0 :28,0 = 6,96
- A dug well next to the hotel - Na/K = 124,0:19,0 = 6,52



a b

Figure 3. Diagram of the anionic (a) and cationic (b) composition from chemical analyses from the surroundings of Kumanovska Spa

1. A dug well next to the hotel, 2. A spring above a pool, 3. A dug well v. Proevce, 4. Borehole Hunting home, 5. and 6. Analysis from G. Kotevski [6]

Water catchment facilities

In the narrower area of the Proevce locality, in the current state, four (4) main springs with thermo-mineral water are registered, of which three (3) are natural and one (1) is a borehole with an artesian outflow [7].

In order to define the method of connection and the yield of the sources, a hydrometric measurement of the yield was performed, and the obtained results are shown in Table 3.

Table 3. Measurement of yield and some other parameters

Object	Artesian borehole S-1 (catchment 1)	Natural well on the road (catchment -2)	Natural spring in spa	Natural spring (2 taps)	Uncaptured free flow from catchment -1 in taps
Yield	Q = 1,8 l/s	Q = 0,7 l/s	Q = 1,8 l/s	Q = 0,2 l/s	Q = 0,8 l/s
Temperature	31°C	31°C	30°C	28°C	30°C
pH	6.7	/	/	6.65	6.64
Electrical conductivity (µS/cm)	2263	/	/	2315	2269
Salinity (PSU)	1.45	/	/	1.47	1.45
Total solids (ppt)	1.81	/	/	1.82	1.81
Density (g/cm^3)	1.00	/	/	1.00	1.00

The total yield of all measured sources amounts to Q = 5 l/s.

Model of the Proevce hydrogeothermal field

From the conducted geological, hydrogeological, engineering-geological research of the Proevce locality, as well as according to the conducted analyses, a predictive geothermal model of the "Proevce" hydrothermal system was made (Fig. 5) [5].

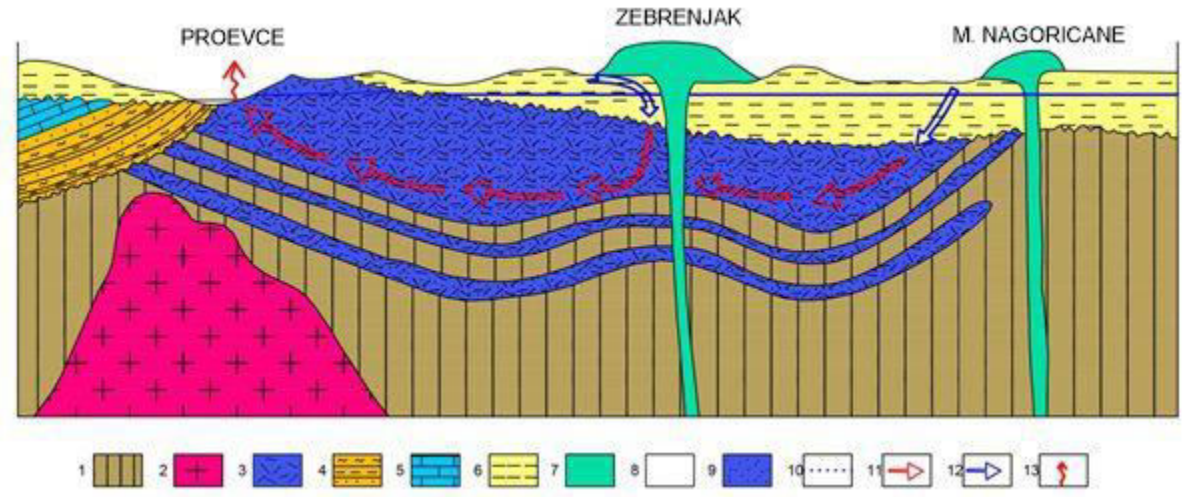


Figure 4. Predictive model of the hydro-geothermal system "Proevce"
1. Shists (floor insulator), 2. Granites (heating body), 3. Marbles (collectors), 4. Flysch, 5. Limestones, 6. Pliocene sediments (roof insulators), 7. Basalts, 8. Alluvion, 9. Hydrothermal reservoir, 10. Assumed level of source waters, 11. Assumed direction of movement of thermal waters, 12. Assumed direction of movement of cold waters, 13. Thermal spring.

Water quality and usability

For more than 80 years, Proevce thermo-mineral waters have been used in balneological – therapeutic treatments in the Kumanovska spa, and, as they are very pleasant and with a special taste, they are also widely used as natural mineral water for drinking.

During that long period, numerous analyses were made by various institutions and experts, which practically confirmed the quality of this water.

Based on the analyses carried out and according to the analogy with similar waters in the world, thermo-mineral waters from the Proevce locality can be used in the treatment of diseases of liver, stomach, intestines, metabolism, and urinary tract.

This water has already been proven in the treatment of diseases of the nervous system, especially the central one (thanks to the content of magnesium and potassium) and in the prevention of stone and sand formation in the urinary tract (also thanks to the magnesium and the alkalinity of the water) [8].

Cobalt, together with copper, as a trace element, and the presence of iron play a special role in the creation of erythrocytes, stimulates growth processes, helps in the recovery of old and frail people, pregnant women, mothers with infants, etc.

The content of manganese in this water helps in the treatment of diabetes patients, in the creation of hemoglobin it stimulates the body's protective forces, it helps in the treatment of liver diseases and more.

The temperature of the water is very suitable for the respiratory and digestive tract, and the taste is particularly sour and pleasant to drink.

Table 4. Results of laboratory tests of the thermo-mineral water from the locality v. Proevce [8]

Examination feature	Examination method	Unit	Result	Reference values
Electrical conductivity	ZZ202	mikr.Scm^{-1}	2550	/
pH	SRPS ISO EN: 2013		6,72	/
Nitrates NO_3	ZZ206	mg/l	< 1,0	≤ 50
Nitrites NO_2	ZZ207	mg/l	< 0,005	≤ 0,1
Fluorides F	ZZ210	mg/l	< 0,2	/
Chlorides Cl^-	SRPS ISO 9297: 1997	mg/l	42,0	≤ 250
Sulphates SO_4^{2-}	ZZ 245	mg/l	34,7	≤ 250
Sulphides H_2S	ZZ 245	mg/l	< 0,004	without
Cyanides CN^-	ZZ 211	mg/l	< 0,01	≤ 0,07
Bicarbonates (HCO_3^-)	III 13	mg/l	1811,7	/
Disolved CO_2	III 14	mg/l	792,0	/
Al	ZZ 221	mg/l	< 0,1	≤ 0,2
Ni	ZZ 220	mg/l	< 0,01	≤ 0,02
Na+K	ZZ 220b	mg/l	235,3	/
K	ZZ220b	mg/l	29,3	/
Ca	SRPS ISO 6058:2000	mg/l	308,0	/
Mg	ZZ 220c	mg/l	45,1	/
Fe	ZZ 220	mg/l	< 0,10	/
Mn	ZZ 220	mg/l	< 0,05	≤ 0,5
Cu	ZZ 220	mg/l	< 0,05	≤ 2,0
Zn	ZZ 220	mg/l	< 0,05	/
Ba	ZZ 221	mg/l	< 0,05	≤ 0,01
As	ZZ 222 B	mg/l	< 0,005	≤ 1,0
Cd	ZZ 220	mg/l	< 0,002	≤ 0,003
Pb	ZZ 220a	mg/l	< 0,005	≤ 0,01

Hg	ZZ 222a	mg/l	< 0,005	≤ 0,001
Se	ZZ 222 B	mg/l	< 0,002	≤ 0,01
Sb	ZZ 220 A	mg/l	< 0,002	0,005
Cr	ZZ 220	mg/l	< 0,02	0,05

CONCLUSION

From all the above, it can be concluded that the investigation area s. Proevce is located southeast of Kumanovo, on the left side of the road leading to St. Nikole, in the river terrace of the Kumanovska River.

In the research area, there are three significant springs with thermo-mineral water, as well as several secondary ones. They are:

- An artesian borehole labeled as S – 1 and it has a yield Qmax = 1.7 l/s and a temperature of 31°C.
- Natural spring with water catchment K – 2 with Q = 0,8 l/s and temperature of 30°C.
- Spa spring in the spa has a capacity of approximately Q = 1,8 l/s and temperature of 31°C.

In the research area, there are also natural uncaptured springs on the banks of the Kumanovska River, for which the yield and temperature cannot be accurately determined because they drain into the riverbed.

The total yield (capacity with self-efflux) of the thermo-mineral water from the existing water catchments amounts to a total of about 4,3 l/s.

According to its chemical composition, the water is hydrocarbonate - sodium-potassium weakly magnesian. Water mineralization ranges from over 1 mg/l to 2,5 mg/l. It contains dissolved CO_2 of 1,205 - 1,504 mg/l.

According to the hydro-chemical and balneological tests and analyses, the water from this deposit meets all the requirements for the use of water for drinking and treatment, according to the applicable legal provisions and many years of practical research.

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ХИДРО-ГЕОТЕРМАЛЕН МОДЕЛ НА ЛОКАЛИТЕТОТ ПРОЕВЦЕ, РЕПУБЛИКА СЕВЕРНА МАКЕДОНИЈА

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Резиме

Во трудот се прикажани резултатите од истражувањата на хидротермалниот систем „Проевце", кој се наоѓа во близина на Куманово. Теренот на кој се јавуваат термоминералните води претставува левиот брег на речната тераса на Кумановска река, над која стрмо се издига Голем рид изграден од старо палеозојски мермери и шкрилци.

Истражувањата покажуваат дека на истражниот простор постојат три позначајни извори со термоминерална вода: артерска дупнатина S – 1, природен извор со каптажа К – 2 и бањски извор. Според својот хемиски состав водата е хидрокарбонатна - натриско-калиска слабо магнезиска.

Според извршените хидрохемиски и балнеолошки испитувања и анализи, водата од оваа наоѓалиште ги задоволува сите барања за искористување како вода за пиење и лекување.

Клучни зборови: *Проевце, термоминерална вода, термален извор, модел, хидрохемиски особини*