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Assessment of Hydrogeological and Hydrochemical Conditions in Kazanlak Basin (Bulgaria)

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ABSTRACT

Kazanlak geothermal basin is located in Central Bulgaria. It is an intermountain depression covering an area of about 780 km^2. Tectonically it represents a graben formed by bordering faults from the surrounding mountain ridges (Balkan mountain to the north and Sredna gora to the south). The basin has an extensional tectonic setting and is characterized by active subsidence and uplift of the surrounding mountain chains.

The four geothermal fields in Kazanlak basin, located along the Tundza River from west to east, are as follows: Pavel banya, Ovoshtnik, Yagoda and Korten. All of them are associated with intrusive Paleozoic granites. Geothermal water is accumulated in the granite rocks, which are covered by Pliocene-Quaternary sediments of different thickness in each area. Water temperature is varying in the range of 33 to 78^{o}C and the total flow rate amounts to about 88,2 l/s.

The current assessment of hydrogeological and hydrochemical conditions of the region is based on information acquired from various explorations (geological, hydrogeological and hydrochemical) provided by many sources. Zones of different chemical characteristics are formed in the region. Thermal waters are currently used mainly for balneotherapy and relaxation. Special attention is paid to further possibilities of thermal water utilization in the region.

1. INTRODUCTION

Kazanlak geothermal basin is located in the central part of Bulgaria in the valley of roses. The region is famous for the excavation of many Thracian tombs dated from the V c. BC to the III c. BC, which are included in the World Heritage List.

The current study is focused on four geothermal fields – Pavel banya, Ovoshtnik, Yagoda and Korten, located from west to east in Kazanlak valley, Fig.1. The geological exploration started at the end of 19th century (Ivanov, 1896, Chernozemski, 1897, Rusev, 1909, Petrov, 1932) but more detailed study has been carried out after the late 1950s (Shterev, 1964, Petrov et al., 1970).

The present analysis is based on the existing geological, hydrogeological and hydrochemical information. Geothermal waters are formed in granite bedrocks which are found at depth of about 9 m on the east (Korten and Yagoda) down to 638m on the west (Ovoshtnik). Natural geothermal springs exist in the four areas and some more hydrothermal sources have been discovered by drilling there. Geothermal application is taking place in four sites as one of them is a town of Pavel banya (3000 inhabitants) and the other three are villages – Ovoshtnik, Korten and Jagoda. Thermal water has been used since Roman time and some ruins of Roman baths were found in Pavel banya town.

During last years many mountain and spa resorts in Bulgaria marked a rapid development due to the renovation of existed spa centers and building of new hotels and places of entertainment in them. Presently, thermal waters are used more intensively for relaxation, prevention and rehabilitation. The treatment of diseases of orthopaedic system, traumas and disorders of the central and peripheral nervous system has a long tradition in Pavel banya town. First steps in thermal water use for bathing were made there in 1923. New complexes for relaxation including indoor and outdoor swimming pool have been built in Ovoshtnik and Jagoda villages. Thermal water in the region is of radon-fluoride-silica type. The highest fluoride content in Bulgarian thermal waters is measured in Ovoshtnik – 24 mg/l. This type of water requires good knowledge of it properties, which should lead to the most suitable scheme for their application, particularly in balneology.

The aim of the paper is to present an interpretation of hydrogeological and hydrochemical conditions and to provide a good background for the most suitable types of application in the region.

2. HYDROGEOLOGICAL BACKGROUND AND CURRENT THERMAL WATER APPLICATION

The geological structure is represented by a graben surrounded by the Balkan horst to the north and Sredna gora horst to the south, Fig.1.

Geothermal water of the four geothermal fields is accumulated in the granite rocks of Paleozoic age, covered by Pliocene-Quaternary sediments, which are of different thickness in each area (Fig.2, Table1). The basin represents a typical fractured hydrothermal zone with steady thermal water temperature. According to Tsankov et al. (1995) two different granitoid plutons are developed in the recharge zone respectively in the western part of the basin (Pastrina pluton) and in the eastern one – Kazan pluton. They have similar mineral composition, but Kazan pluton is more tectonically broken and contains more accidental inclusions. This fact results in water composition variation defined for the both parts of the basin. Korten field is distinguished from the other three as it is located along a fossilized fault, which intersects granites, sediments and volcano-sediment rocks.

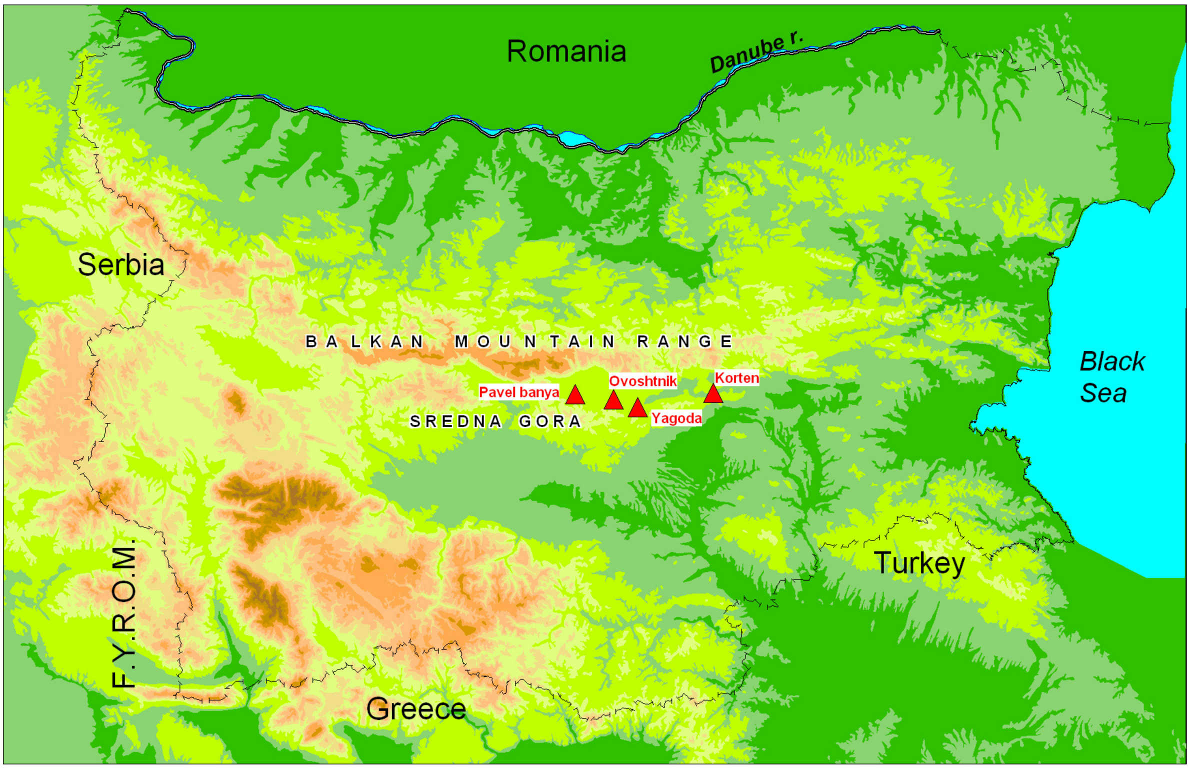

Figure 1: Location map

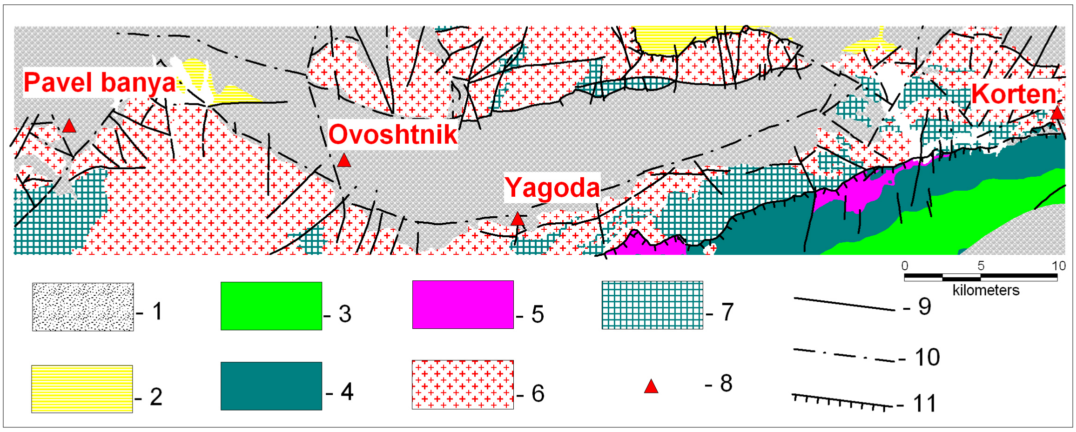

Figure 2: Geological setting of Kazanlak geothermal field

1. - Quaternary deposits; 2 - Paleogene molasses materials; 3 - Cretaceous volcanic and volcano-sediment rocks; 4 - Mesozoic terrigenous and terrigenous-carbonate rocks: 5 - Triassic carbonate rocks; 6 - Paleozoic granite and granitoid; 7 - Proterozoic gneiss and schist; 8 – geothermal field; 9 - Faults; 10 - Fossilized faults; 11 – Overthrust

Geothermal water is of meteoric origin and the main recharge zone is Sredna gora Mountain located on the south of the basin. The precipitation travels a long distance down in the rocks through a system of faults resulting in water temperature increases and formation of its chemical composition. Part of geothermal water ascends back to the surface and occurs as natural springs or is discovered by drilling. The static water reserve in the geothermal fields is limited and the exploitation could be based only on dynamic resource. Hydraulic connection exists between water sources in each geothermal field.

Thermal water in Kazanlak basin was initially produced by 21 geothermal wells (Table1) and several natural springs. The studied area is presently characterized by a total flow rate of about 88,2 l/s and temperature varying in the range of 33 to 78^{o}C, Fig.3. Temperature variation is associated with the depth of incoming water flow from the granites or with the secondarily accumulated water in the overlying Pliocene sediments. The highest water temperature presently measured in Ovoshtnik is 78^{o}C.

Hydrogeological parameters in Kazanlak basin are defined by pumping tests only for Pliocene-Quaternary sediments. Permeability coefficient varies from 32 to 266 m/d and the average transmissivity changes from 20-25 up to 800-1000 m/d^{2}.

Table 1. Geothermal Drilling in Kazanlak Basin.

Geothermal field	*Water source (well)*	*Depth of granite, m*	*Depth of wells, m*
Pavel banya	W-1	87	
Pavel banya	W-2	51	
Pavel banya	W-7		655
Pavel banya	W-8		696
Ovoshtnik	W-1	490	658
Ovoshtnik	W-2	393	588
Ovoshtnik	W-3	558	694
Ovoshtnik	W-4	638	885
Ovoshtnik	W-5	258	427
Ovoshtnik	W-12	165	340
Ovoshtnik	W-14	304	338
Yagoda	W-1	18	150
Yagoda	W-15	9	178
Yagoda	W-16	15	73
Yagoda	W-17	23	251
Yagoda	W-18	30	250
Korten	W-1	9	495
Korten	W -3		503,4
Korten	W -19		100
Korten	W -20		150
Korten	W -21		100,1

- Pavel Banya Geothermal Field

About 9 natural springs were found in Pavel banya field as seven of them manifested stable flow rate and temperature in time. The highest water temperature before drilling was measured in the spring Kademliata – 50,5°C. Water from all springs was connected to a pipeline system during 1930. About 15 shallow wells up to 30 m depth and 4 deeper wells (more than 100 m) had been drilled until 1969. The highest depth of about 700 m was reached by well No8 (Table 1). The granite basement in the field was found at a depth of about 50 to 90 m. The total flow before drilling was 6 l/s but it increased about three times after it. Three wells (3, 7 and 8) are presently in use with water temperature 61°C and total flow rate – 20,6 l/s.

The Pavel banya resort is of national importance. The transitional continental climate creates conditions for all the year round hydrotherapy. It has been developed as a remedial and rehabilitation centre for treatment of diseases of the motor system, orthopedic ones, traumas and disorders of the central and peripheral nervous system.

Water is used for rehabilitation and treatment in spa polyclinic, sanatorium and in several spa hotels Fig.4.

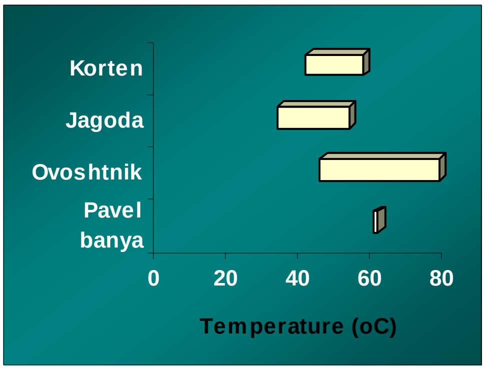

Figure 3: Water temperature range for currently used sources in Kazanlak basin

Figure 4: Spa center and indoor swimming pool in Pavel banya town

Figure 5: Ovoshtnik aqua park

Figure 6: Indoor swimming pool in a spa hotel (Jagoda)

- Ovoshtnik Geothermal Field

Only one hot spring existed in Ovoshtnik area but after an earthquake in 1920, a new one appeared. Six of the seven drilled wells are currently in use. The main reservoir (granite rock) was reached at 300-350 m depth. The total flow is now about 40 l/s of a wide temperature range (45–78)°C, Fig.3. Recently a modern aqua park has been built in the immediate vicinity of the mineral springs.

The complex covers an area of about 2ha and has 5 swimming pools of 50 m in length filled up with thermal water, Fig.5.

- Yagoda Geothermal Field

Initially one natural spring existed in the field, which was lately taped. Drilling for hot water began in 1961 when 5 wells between 73 and 250 m deep were drilled. Currently only three of them and a taped spring are in use and produce about 14 l/s geothermal water of temperature in the range of (33-53)°C. A new spa hotel using thermal water for rehabilitation in tubes and swimming pools has been recently built, Fig.6. A new complex of 11 villas has been also completed in the vicinity of the village. A permit for geothermal energy application for space heating was obtained by a private company in 2008.

- Korten Geothermal Field

Thermal water has been flowing into the nearest river before being taped. Five wells were lately drilled and the deepest of them reached about 500 m. Discovered geothermal water nowadays comes from two wells and one taped spring and its temperature is in the range of (41-57)^{o}C and of about 14 l/s total flow rate. Thermal water is used for relaxation.

About 20% of the discovered geothermal waters are currently used in Bulgaria (Bojadgieva et al., 2005). Kazanlak geothermal basin is not an exception, as only in Pavel banya the used flow reaches 33%, while for the rest it is in the range of 10 to 16%. Thermal water utilization is better developed in Pavel banya and Ovoshtnik, compared to the other two sites, (Fig. 7).

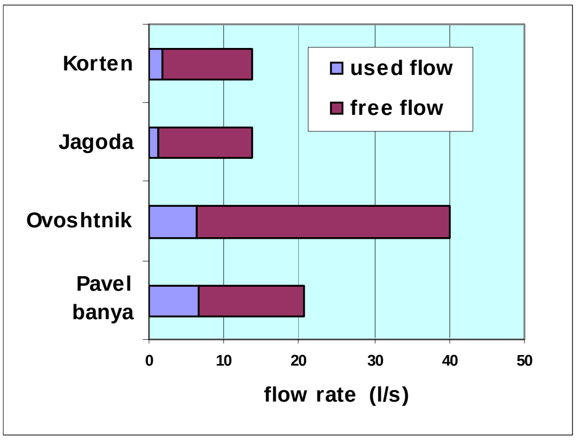

Figure 7: Free and used thermal water flow in Kazanlak field

3. COMPARATIVE ANALYSIS OF CHEMICAL WATER COMPOSITION AND APPLICATION PROSPECTS

All available data on chemical composition of existed natural springs and geothermal wells in Kazanlak basin have been processed and analyzed.

Thermal water composition is formed by the host granite rocks. It is of radon-fluoride-silica type in Pavel banja, Ovoshtnik and Jagoda and of fluoride-silica type - in Korten, (Karakolev, 1990). This is associated with the tectonic processes taking place in the eastern Kazan pluton (Korten field). The range of total dissolved solid (TDS) variation in the four geothermal fields is presented on Fig. 8. Water is of low mineralization and with exception of Korten (900 mg/l) it varies in a narrow interval – from 500 to almost 700 mg/l.

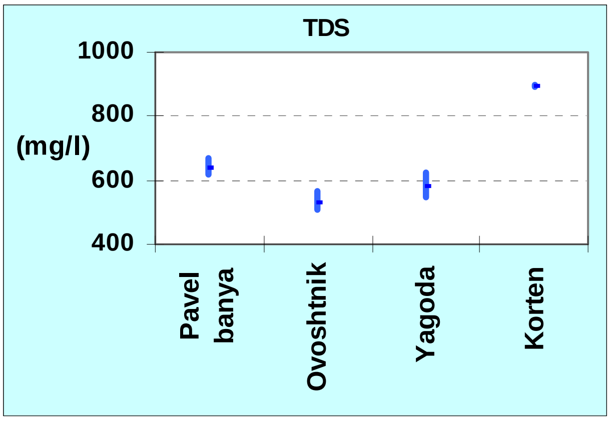

Figure 8: Total dissolved solids variation

Waters in the western and eastern part of the basin are of different macro components as well: Na-HCO_3 is prevailing in Pavel banya and Ovoshtnik fields (western part), while Na-SO_4 - in Yagoda and Korten fields (eastern part), (Fig. 9), (Hristov,1993). The presence of xenolits from different rocks in Kazan pluton (eastern part) resulted in sulfate increase in return to hydro carbonates.

Water is fresh and pure but not potable and should be used for drinking in prescribed doses. According to the Water Law application for healing and prevention activities has the first priority in giving permits. In this instance taking into account the comparatively high temperature of thermal waters for Bulgarian conditions and existing flow rate (Fig.10), geothermal energy should be used in a cascade system including treatment.

Radon radioactivity distribution is presented on Fig.11. It decreases from west to east and reaches the lowest values in Korten field (44,4 Bq/l), (Vladeva et al.,2000). Water in the basin is considered to have low to middle radioactivity.

Radon is a gas, which is a product of radioactive decay in the earth strata and is soluble in water. Its period of half-life is about 3,8 days. Alfa rays are prevailing and they stimulate and regulate the cells function of the body. Radon is released from the human body in several hours through the lungs. Waters of radon concentration more than 1480 Bq/l are not recommended for swimming pools (Karakolev, 1990), which is not the case in Kazanlak basin, Fig. 11.

Thermal waters are also distinguished by their highest fluoride and H_2SiO_3 content among the ground waters in the country. That makes them extremely suitable for treatment of various diseases. Fluoride content in the basin varies from minimum 14 mg/l (Jagoda) to maximum of 24 mg/l (Ovoshtnik), Fig.12. According to Boyadjiev (1991) the enhanced content could be associated with the presence of apatite in the rocks, which varies from 0,07 to 0,24%. According to the national standard for potable water, the fluoride content shouldn't exceed 1,5mg/l. It is proved that its availability in the mineral waters is effective in twice smaller doses compared to drugs for fluoride prophylaxis, but it should be used only according to specialized treatment instructions. Application of fluoride containing water covers caries prevention, osteoporosis, kidney disease, etc. Water is not suitable for bottling as the maximum allowed fluoride concentration is 8 -10 mg/l, (Karakolev, 1990).

The content of H_2SiO_3 runs from minimum 36,7 up to 107,1 mg/l, Fig.13. The enhanced quantities are probably related to the high water temperatures and the silica presence in the granite rocks. Wide spectrum of diseases are affected by the availability of H_2SiO_3 - gastric-intestinal, skin, intoxications with lead, mercury, manganese, etc., degenerative disorders and others.

Waters in Kazanlak basin have a rich mineral composition which covers wide spectrum of diseases, but the treatment with them should be based on a strict scientific approach.

The steady thermal water composition has been proved by providing regular chemical analysis of bottled water within a period of 30 month, Fig.14. All available chemical data, accumulated for a long period of about 100 years have been processed and presented on Fig.15. Water samples are taken from different water sources in different time.

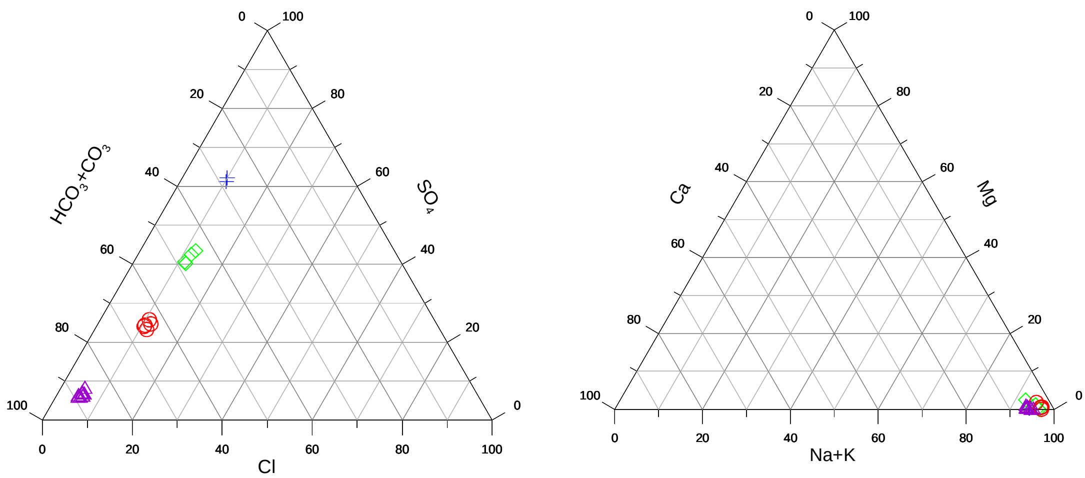

Figure 9: Macro components variation + - Pavel banya;) - Ovoshtnik; (- Yagoda; + - Korten

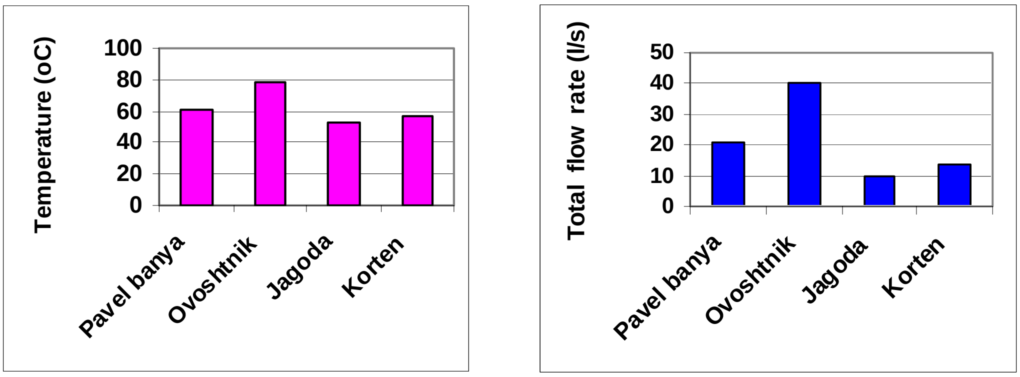

Figure 10: Maximum water temperature and total discovered flow rate in the four fields

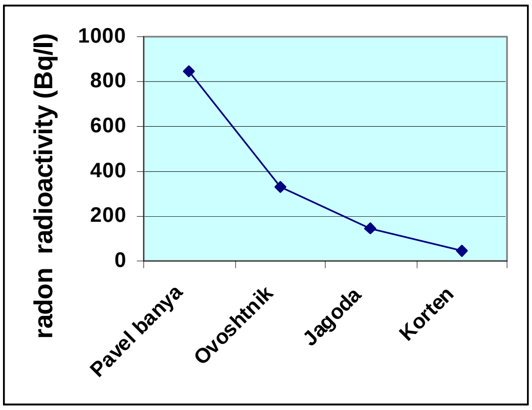

Figure 11: Water radioactivity variation

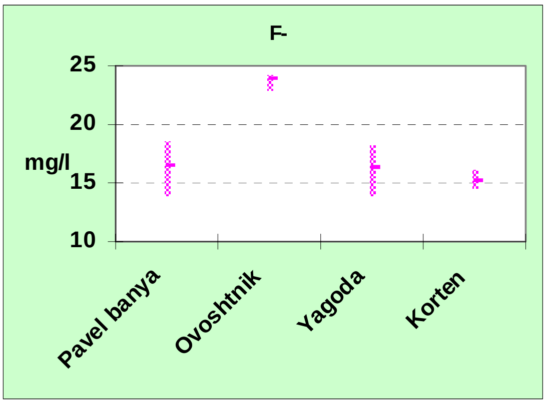

Figure 12: Fluoride content variation

The ratio σ/X_{ave} (where σ is a standard deviation and X_{ave} is the average value of the respective parameter) is less than 20% within the limits of one geothermal field, which confirmed the stable chemical composition in time.

Generally, geothermal water is clean, fresh, with stable chemical composition and stable temperature of the all sources, which creates a reliable base for future balneological use.

4. POSSIBILITIES FOR FUTURE GEOTHERMAL WATER APPLICATION

Currently leading applications in terms of water quantity and quality are in balneology - for drinking in prescribed doses, for treatment in tubes and pools, for showers, irrigation and inhalations. The water is also used in the newly built swimming pools in the existing resorts. Future applications should include production of fluoride concentrates, utilization of geothermal energy for space heating and domestic hot water.

A project “Identification of key barriers for the utilization of the national geothermal resources in Bulgaria and site case studies for Velingrad, Sapareva banya and other geothermal heating systems” has been completed by COWI, Denmark and EcoPro Consult, Bulgaria. It was financed by a grant received under the Japan Climate Change Initiative Programme – Japanese Trust Fund. Case studies have been developed for 11 most prospective geothermal reservoirs in Bulgaria. Among them were Pavel banya and Ovoshtnik. Appraisal for geothermal station of 950 kW installed capacity assisted by plate heat exchanger (60/35°C) and using geothermal water 62/40°C has been made for Pavel banya. Another case study for Ovoshtnik is completed including construction of geothermal station of 470 kW installed capacity, assisted by plate heat exchangers (48/35°C). The investment costs for Pavel banya are expected to be about 134 832 EUR and 93 068 EUR - for Ovoshtnik. The pay back periods are respectively about 11 and 20 years (COWI, 2005).

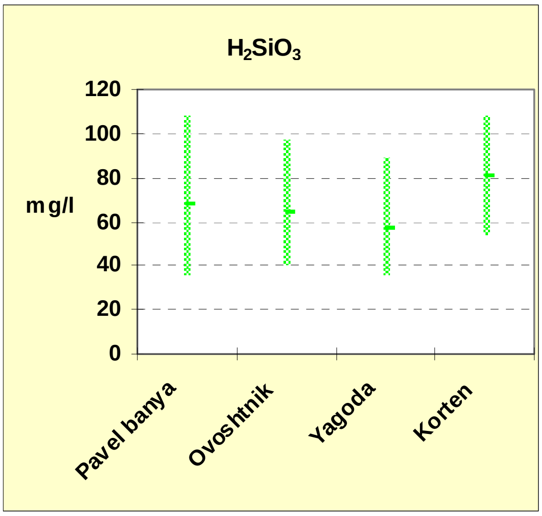

Figure 13: H_2SiO_3 content variation

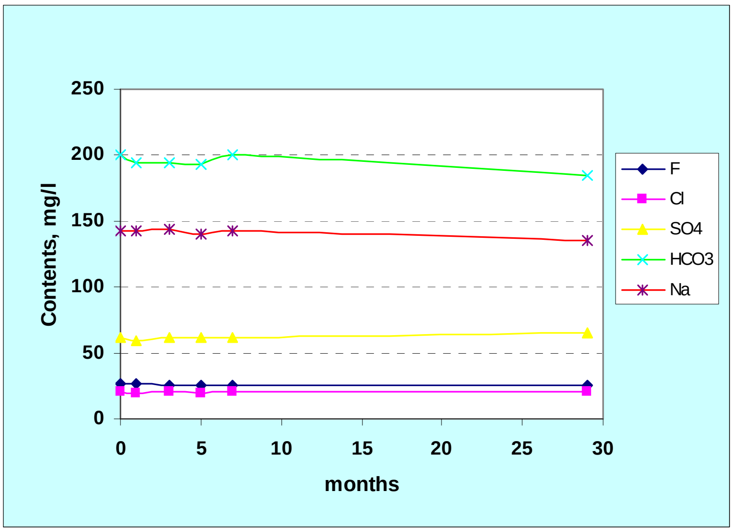

Figure 14: Variation of chemical composition of bottled water in time

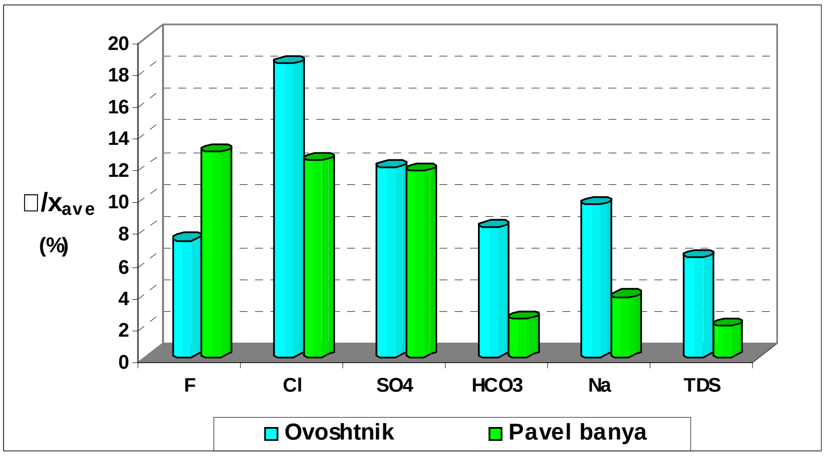

Figure 15: Standard deviation of average value of thermal water chemical indicator for a period of 100 years

(where **σ** is a standard deviation and $\mathbf{x_{ave}}$ is the average value of the respective parameter)

CONCLUSIONS

Geothermal waters in Kazanlak basin are micro-biologically clean, fresh and with low total dissolved solids.

Water mineral composition is rich and covers wide spectrum of diseases but require following a strict treatment methodic. Water chemical composition has been preserved unchanged for a period of 100 years, which creates a reliable base for balneological use.

Static water resource of the basin is limited and dynamic one should be considered as a base for exploitation.

Maximal measured temperatures in the four fields vary from 47 to 78^{o}C and considerable difference exist in the available flow rate - from 13,7 to 40 l/s.

The highest thermal water utilization exists in Pavel banja resort (33% of the total discovered flow rate), while it is between 10 and 16% for Ovoshtnik, Jagoda and Korten sites.

Geothermal water in Kazanlak basin is not suitable for bottling of potable water or soft drinks because of a very high content of fluoride but it could be used for treatment of many diseases in prescribed doses.

Pavel banya and Ovoshtnik have better prospects for geothermal development compared to the other two. Case studies for geothermal energy use have been completed for them and two geothermal stations of 950 kW and 470kW could be built in future.

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