Geology and Utilization of Porous Thermal Water Reservoirs, NE Hungary

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ABSTRACT

Porous thermal water reservoirs of Pannonian successions in north-east Hungary could have more significant role in the region's economic, energetic, environmental and health care sectors than nowadays. In order to estimate the potential and to ensure sustainability studying porous thermal water reservoirs is necessary.

General utilization of thermal water in Hungary, especially when extracted from porous reservoirs, is overviewed in this paper.

General geological concept and more detailed model of the study area focusing on local variability are presented in the frame of this research. As a result, specific areas which can be called as subregions can be defined and each has its own special characteristics distinguishing one from the other and each represents a specific potential. This system is based on geological properties especially geometry (depth, thickness, width), tectonic characteristics and facies analysis (homogeneity investigations: mapping isopic and heteropic units).

By analysing production data of thermal wells significant information can be extracted about reservoirs. Amount of extracted water, both static and operating water level values, well head temperatures, geothermal gradient values were studied.

1. INTRODUCTION

Thermal water has been extracted and utilised from the porous thermal water reservoirs of the Pannonian successions in the north-east part of Hungary for many decades (Buday et al. 2015, Horváth et al. 2015). Well head temperatures vary in approx. 30-80 °C depending on screening depths. Average geothermal gradient value is higher than 50 °C/km. Total dissolved solid (TDS) content and gas content of the wells show high variety, but in general it can be stated that thermal water extracted here has high TDS content. Thermal water extraction data show lower static water level and operating water level by time in wells in many cases. In addition, differences between the wells of neighbouring cities can be detected.

There are also certain challenges occurring in NE Hungary people have to face with such as commitment to reduce greenhouse gas emission and to use renewable energy in higher ratio, increasing irrigation needs, groundwater table decrease or developing an integrated urban water system.

2. DATA AND METHODS

Study area is located in the Tiszántúl region, north-east Hungary. Settlement density is moderate in this area and all of the towns have one or more thermal wells and many have spa (Fig. 1) using thermal water of Pannonian reservoirs.

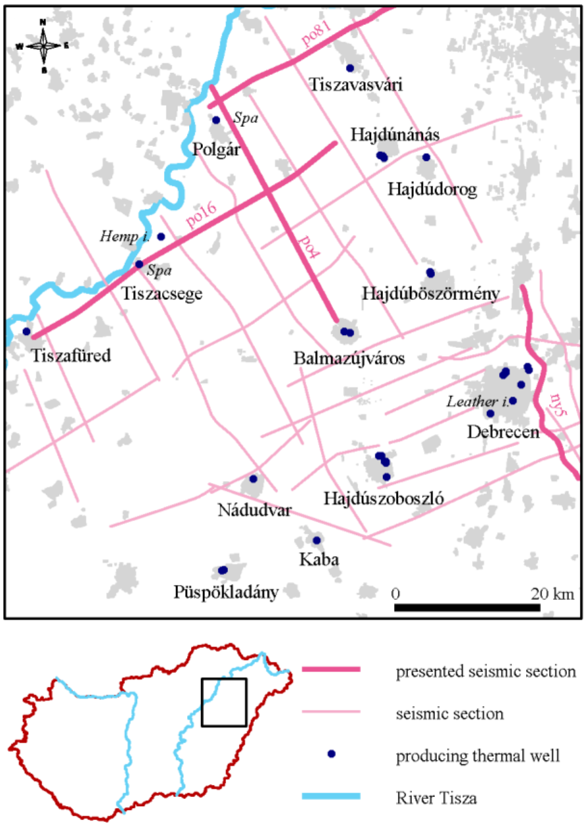


Figure 1: Site map of study area.

2.1 Geology of Pannonian s.l. and geology of the study area

The general filling-up model of Lake Pannon was created in the second half of the 20th century thanks to the improvements of geophysics and complex fluid reservoir researches (Vakarcs 1997, Juhász et al. 2007, Magyar 2010). According to the general filling-up concept basal marls, turbidites, delta slope, delta front, delta plain and fluvial facies constitute a full Pannonian s.l. series. The main dynamics of accumulation was that the rivers flowing from the surrounding mountains to the basin filled it up by constructing delta systems. During this process the shoreline was continually developed forward to the basin centre and sediments of the same facies were deposited on each other with a slight horizontal shift if there were no significant changes in water level and/or the amount of sediment supply.

In distal and deep parts of the basin, up to 1000 m in depth, fine-graded sediments were accumulated: marl, limes, clay progressing slowly. This was named as Endrőd Formation but its occurrence is not general all over the basin due its special facies circumstances (depth, distal position), hence in the present research area these series are missing. In the proximal parts of the basin delta slope was developed the material of which could indicate mass movement easily even at small slope angle. Due to fast mass movement events upward-fining units were re-deposited on the bottom of the delta slope. This allochthonous succession is called Szolnok Formation. The other, autochthonous part of delta slope material is composed of grey clay, silt and a small amount of sand. This latter one is called Algyő Formation. Higher on the delta, on the delta front sand successions and delta plain deposits were accumulated, named as Újfalu Formation and Zagyva Formation, respectively (Horváth et al. 2015).

The Pannonain s.l. successions were affected by syn- and postsedimentary tectonic events resulting in faults and folds, in addition, during compacting inner shearing may be formed. Therefore, some alterations may occur in its geometry compared to the general filling-up concept but the occurrence of these elements is not general, only certain locations are affected.

Sediments originating from the recharge area of the basin can be considered as sequences which are products of accumulation cycles. The patterns within the cycles of the same unit are similar since they follow each other based on similar schemes, repeatedly but usually with more or less different intensity. Since the basin was in an isolated position relative to the world sea, among the traditional sensed sequence stratigraphic modelling elements, which are the eustatic water level changes, subsidence of the basin (parts), sediment supply rate and climatic factors, the last three played a major role.

According to previous research projects filling-up of Lake Pannon can be divided into four main stages: Pa-1 (12–11 Ma), Pa-2 (11–9.1 Ma), Pa-3 (9.1–6.8 Ma), Pa-4 (6.8 – 5.2 Ma?) (Vakarcs 1997). Among these stages Pa-1 and Pa-2 were characterized by a series of subsidence events and turbidite accumulation, while Pa-3 and Pa-4 were the time of intra Pannonian tectonic events and the geomorphological inversion of the basin, water level fall and erosion events.

Pannonian successions developed in the focus area, that is the focus features of the present study, were deposited in the early stages of the Pannonian since its palaeoenvironment represents marginal northeastern part of the basin. Deeper basin zones are not general in this area, but only in some more intensively subsiding parts such as Derecske Trough and the western part of Hortobágy (Magyar 2010). Consequently, there is a lack in deep basin pelagic sediments.

Focus features are considered as different delta environments which can be categorized as different subenvironments or facies which were formed during the process of progradation while the water became progressively shallower by time and a shallowing-up/coarsening-up succession formed.

In the case of shallow water, this is closer than in the case of deeper water and it is also important to note that tide actions, considerable tectonic or storm events can also modify this material. This zone is called the delta slope, which is generally depicted as a steep inclined slope, however, it is rather a gentle slope: in the case of fine-grained deltas a few degrees, in the case of coarse-grained deltas it is 30°.

Finer sediments transported by water usually in suspension enter the more or less still water of the accommodation zone and form deposits distally in a region called pro delta. Delta slope and pro delta are the main delta-front sub-environments.

Delta-top or delta plain is the part of a delta situated between the alluvial plain and the delta-front.

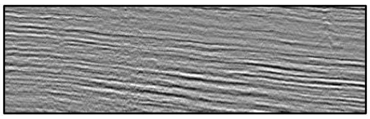
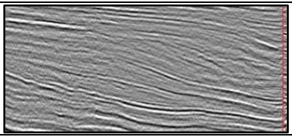
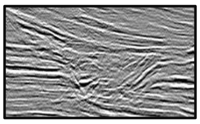
2.2 Analysis of seismic sections

Thirty 2D seismic sections have been analysed. The sections can be classified into two groups based on their strike directions that are perpendicular to each other (NE-SW and NW-SE) (Fig. 1).

During seismic facies analysis facies and facies groups are identified and their main properties (vertical and horizontal sizes) and their position relative to each other are determined. This is based on the fact that each facies has its own seismic characteristics, its own seismic pattern. The main seismic pattern variations occurring in the focus area in Pannonian s.l. succession are shown in Table 1.

Delta plain facies is composed of the varying fluvial deposits with upward fining succession of sand, silt and clay. Its seismic pattern is indisposed, disordered, the velocity changes are frequent. In the Hungarian lithostratigraphic system the succession is known as Zagyva Formation. The upward coarsening succession of the delta front is the alteration of sand and clayey units seismic profile of which can be described as parallel units of vertically varying high and low velocities. This unit is known as the Újfalu Formation in the Hungarian lithostrtaigraphic system. Delta slope facies of the prodelta has an average dipping angle of 5° towards the basin centre and this dip can be identified in seismic sections. It has another main characteristic in the form of a sigmoidal pattern. It is composed of fine graded sediments, mainly silt and clays. It is also known as Algyő Formation. The deepest units of the Pannonian s.l. in the focus area are turbiditic depositions. Its main characteristic is thick layer alteration of units with low and high velocity. This is the Endrőd Formation.

Table 1: Seismic patterns of facies of Pannonian s.l. with formation and sediment characteristics in NE Hungary

seismic pattern	facies group	litostratigraphic unit (formation)	sediment characteristics
	delta plain	Zagyva Fm.	upward fining sediments: sand, silt, clay
	delta front	Újfalu Fm.	upward coarsening sand, clayey sand
	prodelta - delta slope	Algyő Fm.	fine sediments: silt and clay
	deep marine facies	Endrőd Fm.	upward fining sediments: marl, clay and turbidites
	incised valley/submarine canyon	-	sand, mud, silt,

Morphological examinations of the basement are also very important, as the depth and thickness of the accumulated sediment layers are basically controlled by the conditions and the accommodation space characteristics. Two extremities can be observed in the focus area: subareas, where locally thinning outs and subareas where thickening of the Pannonian s.l. can be described. In the case of steep slopes, submarie valleys, canyons and braided channels, slides, relative water level rise are typical. As a result, sedimentation, erosion, discordance, and the progression of the progressive series of isopic facies can occur. They appear locally, and there are several examples in the research area.

Structural elements of the area are also important parts in the analysis and mainly related to basement characteristics. Besides several smaller normal and reverse fault systems, there are some major faults which have significant effects on the geometrical properties of the Pannonian s.l. succession.

2.3 Production data analysis

By analysing production data of the studied wells for years 2007, 2012 and 2017 production data analysis had been carried out. Production data must be reported to the competent water directorate which in this study area is the Trans Tisza Water Directorate yearly. Water level (static and operating), production yield, well head temperature, geothermal gradient, depression rate, water quality test results are listed in the reports, with minor mistakes and missing data. Therefore, during its data management these must be taken into account.

3. RESULTS

3.1. Geological interpretations

Along the seismic sections delta plain, delta front, delta slope of prodelta and deep marine facies were identified from which po4, po84, po16 and ny5 are presented in the present paper (Fig. 2, Fig, 3, Fig 4). From the thermal wells, similarly to seismic sections, a few is presented here. These are Polgár, Spa, Tiszacsege, hemp factory, Tiszacsege, Spa, and Debrecen, leather factory. From them only the Tiszacsege, Spa is screened into delta slope facies, and the other three is screened into delta front, however, Debrecen, leather factory almost reaches delta slope successions.

In seismic section, po4 from western view a fault can be identified in the northern part of the section. This tectonic element divides the delta front succession of the area, to the north of which Polgár, spa well is located while Tiszacsege thermal wells were drilled on the southern side.

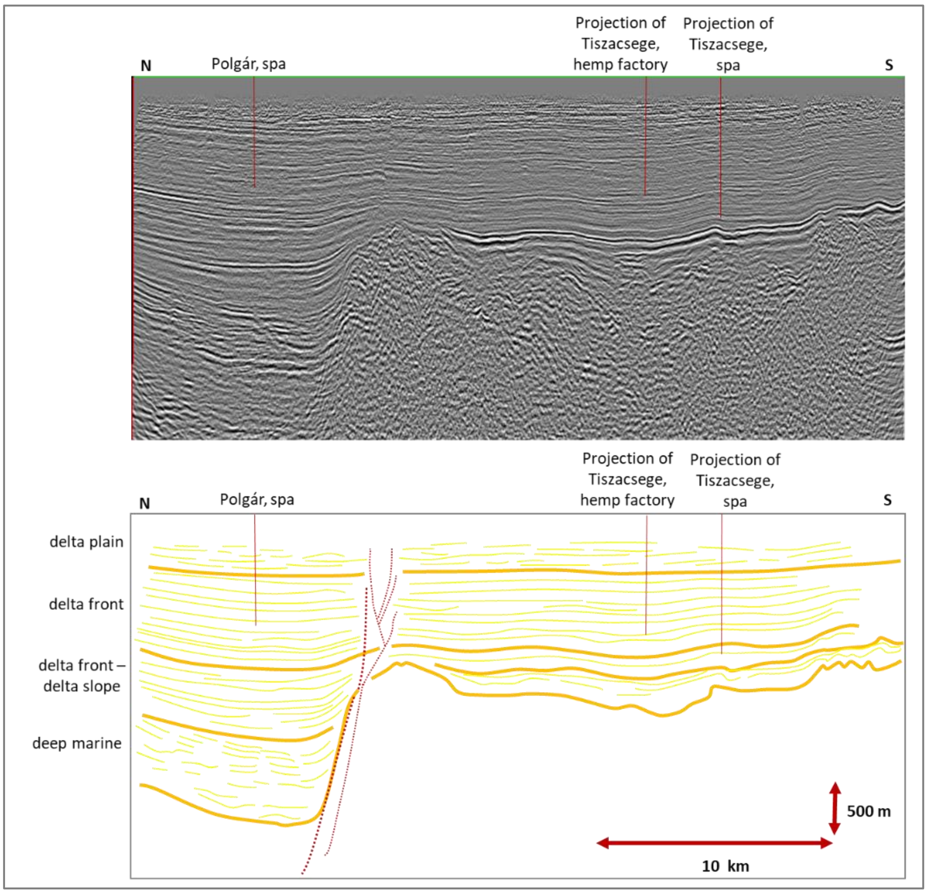


Figure 2: Interpretation of seismic section po4 with thermal well projections of Polgár, Spa, Tiszacsege, hemp factory and Tiszacsege, Spa.

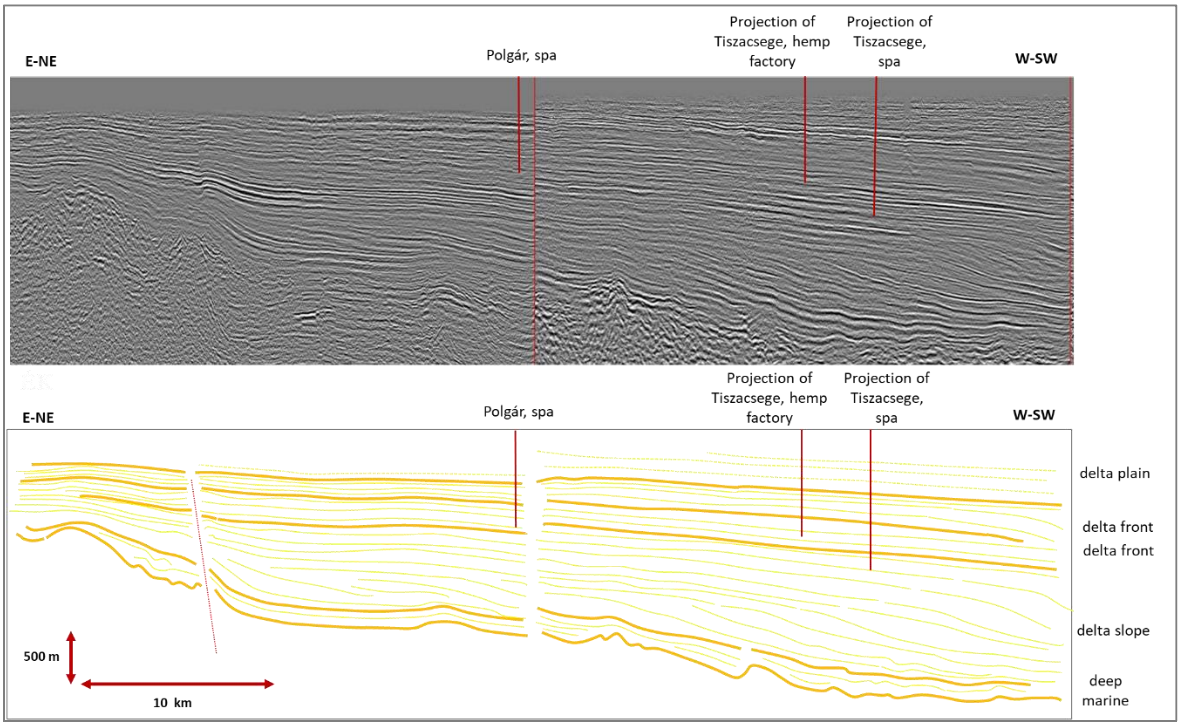


Figure 3: Interpretation of seismic section po81 and po16 (respectively) with thermal well projections of Polgár, Spa, Tiszacsege, hemp factory and Tiszacsege, Spa.

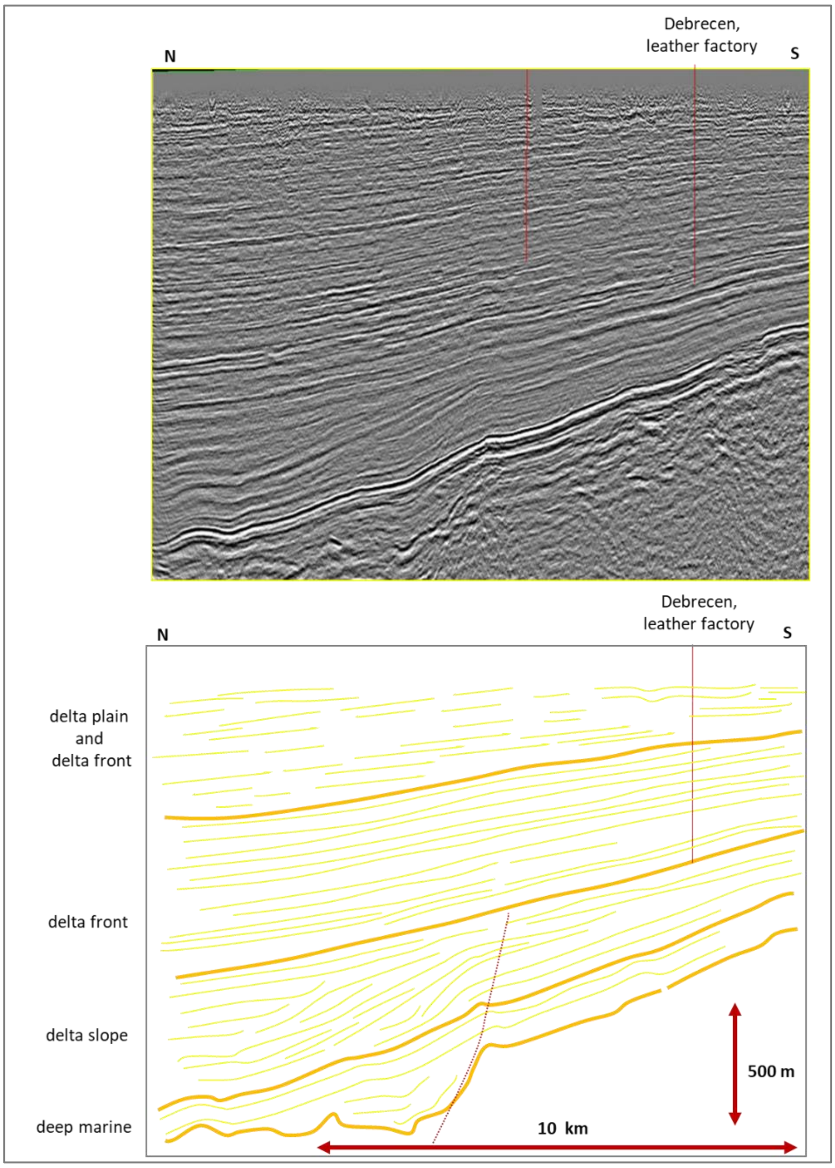


Figure 4: Interpretation of seismic section ny5 with thermal well projection of Debrecen, leather factory.

3.2 Amount of produced thermal water and containing materials

In the studied years thermal wells of 13 towns were operated based on the acquired data (Fig. 1). The overall amount of produced thermal water was 3.85 million m^3 in 2017, a little bit higher than earlier. In addition, considering the unknown number of operating wells this value may reach 4 million m^3/y. The centre of extraction is Hajdúszoboszló with its 15 wells and around 1.75 to 2 million m^3 of thermal water production per year. In addition, Debrecen located in its neighbourhood with an annual water production of around 0.6 million m^3 (Fig. 5).

Yield of most of the wells varies between 450 l/min and 600 l/min. Static water levels of the examined thermal wells vary in a wide range: -10 and -90 m. In the case of wells with greater production rates deeper static water values can be measured as shown by the wells of Hajdúszoboszló (Buday et al. 2015).

Towns with several wells do not use all wells with similar yield in each year. In this case, changing the production yield of the wells helps the recovery of the reservoir. In Hajdúszoboszló there are distinct reservoirs for medical water and for warm water. In 2017 one third of the produced water had temperatures lower than 50 °C. The temperature of the rest varies between 58 °C and 68 °C.

In most of the cases water has high total dissolved solid content (TDS), in the deeper reservoirs this value is higher than 10000 mg/l. The typical TDS is between 2500 and 5000 mg/l. In the shallower reservoirs alkaline hydrogen carbonate type waters are contained, by the increasing depth the portion of the chloride ion increases significantly.

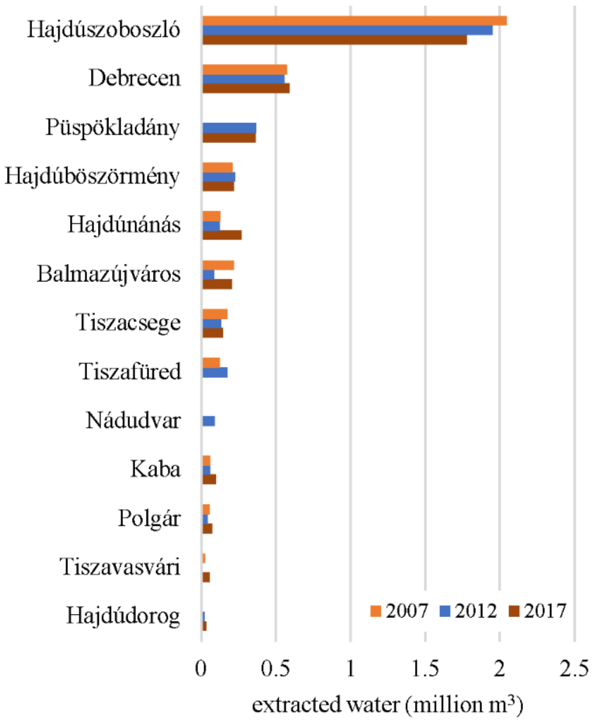


Figure 5: The amount of the extracted water (in million m^3) by the thermal wells listed in years 2007, 2012 and 2017.

The TDS and water type basically depend on the facies in which the sediments were deposited and on the relative connection with the adjacent facies. E.g. sodium and chloride ion derived from marine sediments. Generally, the deeper zones contain thermal water with higher TDS, but at a given depth the TDS content shows a great diversity in the area. In Fig. 6 the position of the screening is presented in the case of 4 wells. One of the wells of Tiszacsege and the Polgár, Spa well have screening at similar depths, but their TDS values show significant differences (Fig. 7). In the case of Tiszacsege, Spa and Debrecen, Leather Factory not only the TDS but the chemical characters are different even though they have similar screening depths. TDS and chemical character are similar in Polgar, Spa and Tiszacsege, Spa even though reservoir depths are not similar like well-temperatures.

Wells with screening at considerably different depths may produce water from different reservoirs with different characteristics (temperature, TDS and chemical character, medical effects, pressure conditions). During water production these reservoirs could behave in different ways, in some cases reservoirs become unproductive, while the other reservoirs serve water, consequently well-head properties could change in time. Only the middle screenings of Polgár, Spa well and only the upper screening of Tiszacsege, Hemp factory well are producing nowadays based on the well tests.

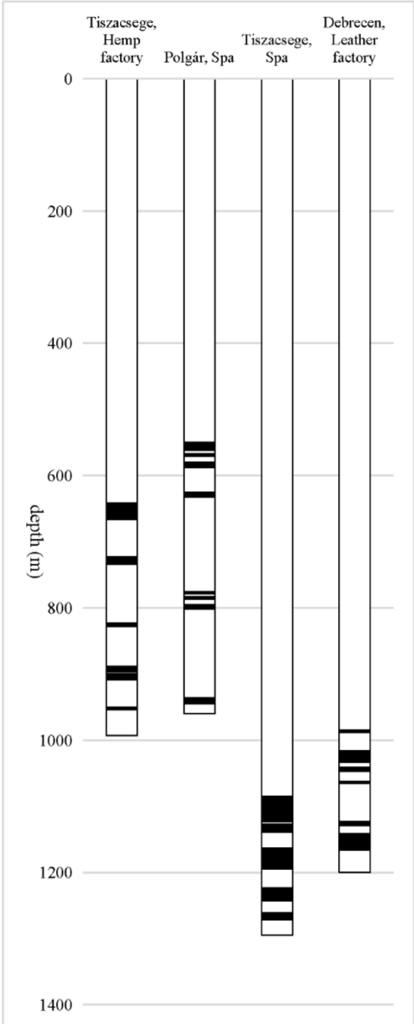


Figure 6: Total depth and screening depths in thermal wells of Tiszacsege, hemp factory, Tiszacsege, Spa, Polgár, Spa and Debrecen, leather factory.

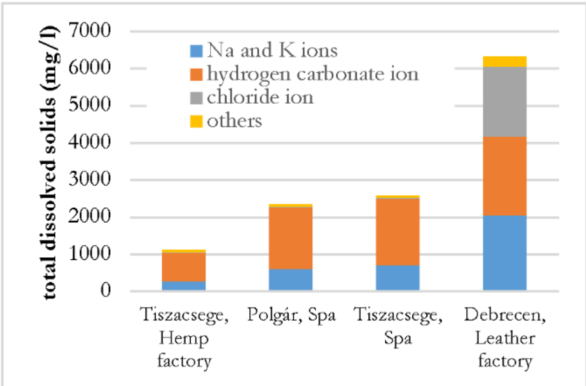


Figure 7: Total dissolved solid content values of the listed thermal wells.

Based on the amount of extracted water and TDS, the produced dissolved solid of the region by thermal wells was around 15000 tons in 2017. Most of the spas drain the used water to cooling lakes and other surface recipients which may have significant effects on the environment.

3.3 Utilization of thermal water

In most cases the produced thermal water used mainly for balneological purposes, partially as medical water. However, this means a wide range of technologies from the little spas with one or two pools running only in summer (such as Tiszacsege, Hajdúdorog, etc.) to the highest level of Hungarospa, Hajdúszoboszló.

In this bathing complex five different types of spas are presented. The thermal spas open during the whole year have both indoor and outdoor pools, the indoor pools are filled with medical water. In addition, medical treatments are also available there. Open-air spa of Hajdúszoboszló is in operation during summer with 13 pools such as swimming pool, wave pool, bubble pool, children's pools. There is an aquapark with water slides near the open-air spa. One of the newest parts of the bath is the aqua-palace indoor pool complex where the pools have unique configuration and decoration. In addition, a swimming pool is also located nearby the spa. In the parts of the bathing complex sauna, solarium, fitness centre, sport facilities and accommodation (hotels and camping) are also available. The capacity of the bathing complex with water surface of 17600 m^2 is around 25000 people.

The typical medical water from the deeper Pannonian reservoirs is alkali chloride, hydrogen carbonate type with additional medical elements such as iodine, bromide and contain significant amounts of calcium, magnesium, metaboric acid, metasilicic acid and in some locations (such as Hajdúszoboszló) organic materials. Bath cure with medical water has effects on the

- chronic joint inflammation
- degenerative joint problems, wearing joint diseases
- different acute inflammatory degenerative problems of spine
- chronic problems, inflammations of the nervous system
- follow-up treatment from any paralyses
- acute muscle pains
- rehabilitation from general and sport injures, certain locomotor disorders
- chronic gynaecological problems, infertility
- acute skin problems
- constriction of blood vessels
- osteoporosis

In several spas the medical treatments are supported by social insurance.

Energetic utilization of thermal water is rare. However, in Debrecen and Hajdúszoboszló complex energetic utilization have been carried out with methane combustion. In Debrecen the following utilisations were developed in order:

- methane extraction
- energy extraction for heating the spa, offices, hotel and restaurant with heat exchangers
- energy extraction for heating the sanitary hot water with heat exchangers
- cooling the water if necessary (e.g. in summer,
- when no heat demand)
- use the water in the pools
- heating the air with the energy of the drain water with heat exchangers or heat pumps
- preheating sanitary hot water with heat exchangers or heat pumps

With this system significant energy saving is possible presenting practice to follow.

4. CONCLUSIONS

Knowledge of geological background of thermal water production is highly recommended in the study area since both the geological environment and production data show high variability. Moreover, explanations of differences or anomalies shown in productions cannot be answered easily. Geophysical methods can be a good tool to gather knowledge about palaeoenvironments and facies properties.

In the early phases of thermal well construction in the area the general filling-up model of the basin was not available, and there was only little information about local geology. Therefore, screenings were carried out inadequately in many cases resulting in unfavourable phenomena such as pressure decrease, corrosion, sand accumulation within wells, screening failure, etc.

In well reconstruction projects and installation of new wells complex studies are recommended to apply in order to fulfil sustainability requirements of production.

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