HYDROGEOTHERMAL RESOURCES IN SPA AREAS OF SERBIA
Main Properties and Possible Improvement of Use

by

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Geological complexity of the territory of Serbia is a world curiosity: six main geo-tectonic regions and tens sub-regions are delineated in a small area of 88,000 km^2. Geologic origin and regional structure of some areas has long been the subject of discussion. Notable magmatism and associated tectonic events in the Earth's crust provided for a fairly large hydrogeothermal resource potential, which is manifested in more than 250 warm (mainly mineral) springs and more than 100 hydrothermal wells. Thermal springs and wells together discharge some 5 m^3/s. This potential is used in part for balneal therapy (waters differ in temperature and chemical composition) in the spa areas of Serbia. The amounts of thermal water unused therapeutically or the amounts of heat energy from unused geothermal water may be used in almost all spas for space heating/cooling and thus increase the efficiency of the thermal water energy utilization. This also will be cost-effective, reduce emission of noxious gases, and improve the environmental-health image of the resorts. The hydrogeothermal resources are described for 29 spas with 700 l/s total discharge capacity of water temperature between 25 °C and 96 °C, or an overall heat energy of 78.40 MW$_t$. Feasibility of additional energy utilization of thermal water in spas is generally considered.

Key words: *spa, thermal water, space heating, energy efficiency*

Introduction

Geothermal energy (GTE) is the heat energy contained in rock masses and fluids in the Earth's crust. There are four major types/forms of GTE resources [1]:

(1) hydrothermal (hot water) geothermal resources,
(2) hot dry rock (HDR), which means high rock temperature but lack of fluid or low rock permeability in the formation,
(3) geopressure is a specific kind of potent geoenergy whose reservoirs consist of three important properties which make them attractive for energetic utilizations: high pressure, high temperature and dissolved methane, and

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(4) magma energy, from the magma bodies relatively close to the earth surface.

The existing technology does not yet allow exploitation the geopressure geo-energy nor the magma energy. Access to the HDR resources involves injecting cold water down one deep drilling well, circulating it through hot and fractured hard rock, and drawing out hot water by another drilling well. Currently, there are no proper commercial applications of the deep HDR GTE [2].

The hydrothermal geothermal energy *i. e*. hydrogeothermal energy (HGTE) is commonly used on land surface either directly from natural hot or warm springs or from drilling wells. HGTE could found the following applications [2]:

– production of electricity, where geothermal power plants use pressure of hot steam from the hot water reservoirs for turbine rotation,
– direct use, by producing heat directly from the captured hot water, for several applications: indoor space heating, balneal use, swimming pools, green-houses, fruit and vegetable drying, fish farming, snow melting, *etc*., and
– geothermal heat pumps (GHP) are used for the heat production from relatively cold groundwater, for the air-conditioning of indoor space mostly.

There are several classifications of GTE resources by temperature [3], established by different authors and institutions and all of these ar consistent with the GTE applications. Generally, it can be adopted that low-temperature hot waters have temperature lower than 90 °C (direct use and GHP), and high temperature (higher than 90 °C) hot waters and steams are used in production of electricity. One of the classifications of GTE use, based on resource temperature, is given in tab. 1.

Table 1. GTE use classifications based on resource temperature [4]

Resource temperature	Best applications for geothermal heat
Surface temperature (5-25 °C)	**GHP:** heating, ventilation and air-conditioning systems for homes and buildings
Low temperature (25-75 °C)	**Direct use:** agriculture and greenhouses, fish farming, spas and bath facilities, district water heating, soil warming, fruit and vegetable drying, concrete curing, food processing
Moderate temperature (75-150 °C)	**Electricity production**: binary fluid generators; **Direct use:** absorption chillers, fabric dyeing, pulp and paper processing, lumber and cement drying, sugar evaporation
High temperature (>150 °C)	**Electricity production; Other:** minerals recovery, hydrogen production, ethanol and bio-fuels production

An estimate of the worldwide installed thermal power for direct utilization of GTE (including GHP) by the end of 2009 is 50.583 MW_t and the used energy is 438,071 TJ/year [5]. The distribution by categories of use is as follows: 49.0% for GHP, 24.9% for bathing and swimming (including balneology), 14.4% for space heating, 5.3% for greenhouses and open ground heating and the rest of app. 6.4% is for other users.

Geothermal outline of Serbia

The territory of Serbia, a surface of 88,000 km^2, takes the central part of Balkan Peninsula. Its geology is quite complex in number and variation of lithologic and timestratigraphic units (from the Proterozoic to the Quaternary) and in structural features. There is not yet complete agreement on the geotectonic regionalization and on geotectonic classification of some parts of the territory. Anyway, the concept of "bilateral orogeny" is widely accepted, with the Serbian-Macedonian (Rhodopean) massif being the crystalline core, and intensive magmatic and tectonic activities in the geosynclinal areas east and west of the central massif [6]. The northern part of the Serbian territory is the Pannonian basin, a large depression filled with thick dominantly clastic sediments.

Geological heterogeneity of the territory is largely a result of strong magmatism and consequent intensive deformations (faulting, folding, thrusting) of Earth's crust during the Cretaceous and the Tertiary (Alpine tectonics), which provided formation of more than 250 major warm and mineral springs [7].

Many exploratory wells were drilled in a search of hydrothermal reservoirs with more abundant warmer and/or mineral water than in natural springs. There are more than 100 hydrothermal water wells in Serbia at present [8], some chance wells from the petroleum or gas (in the Pannonian basin in particular) or ore-mineral explorations.

On the basis of the Earth's crust geothermal characteristics, the geothermal areas recognized on the territory of Serbia are the following:

- northern part of the territory, Pannonian basin, with the less thick crust and terrestrial heat flow density within the range from 80 to 110 mW/m^2 [9];
- southern part, rest of the territory, with generally thicker crust (40 km or less) where terrestrial heat flow density are between 50 and 130 mW/m^2 [8], mainly in the younger, dominantly Tertiary magmatic rocks, and where most hot springs occur.

According to the preliminary assessment [8] total thermal heat power capacity use in Serbia is 100.8 MW$_t$. The various applications include: 39.8 MW$_t$ and 647 TJ/year for balneal use and swimming, 20.9 MW$_t$ and 356 TJ/year for space heating, 18.5 MW$_t$ and 128 TJ/year for greenhouse heating, 6.4 MW$_t$ and 128 TJ/year for fish and animal farming, 4.6 MW$_t$ and 58 TJ/year for industrial process heating, 0.7 MW$_t$ and 10 TJ/year for agricultural drying, and 9.9 MW$_t$, and 83 TJ/year for GHP.

HGTE reservoirs are rocks of different hydrochemical properties and temperatures. Water varies in pH values from 2.5 (hyperacid) to 12 (hyperalkaline) and in total dissolved solids (TDS) from 0.5 g/kg to 20 g/kg. The highest temperatures of hot spring and well waters are 96 °C and 111 °C, respectively. Total discharge of mineral and thermal spring and well waters is some 5 m^3/s [7].

Thermal waters in the spa areas of Serbia

A part of HGTE natural treasure has found application in Serbian spas (fig. 1) where waters of different qualities (temperature and chemical composition) are used in balneal therapy.

In the region including the present-day Serbia, the spa tradition dates back to the Roman age, when hot and mineral springs were used and Roman baths ("terme") were built in at least ten places. The spa Ribarska Banja was a settlement of Roman colonists, and thermomineral water of Vrnjačka Banja was used in a kind of therapeutic centre for Roman legionaries. Some architectural elements of the "terme" establishment remains are conserved in the Niška Banja, Novi Pazar, Sijarinska Banja and Gamzigradska Banja [10]. Old installations for thermal water abstraction, known as "Roman wells" at present, are still found in a few locations. Tradition of using warm and mineral springs continued after the Slavic

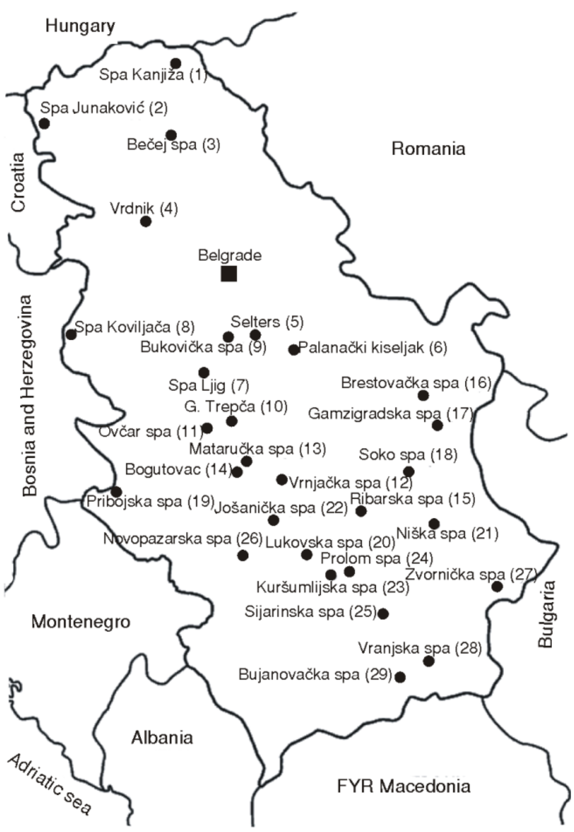

Figure 1. Locations of major spas in Serbia spa development

invasion of Balkan peninsula, during the Medieval kingdom of Serbia. Many monasteries, Crown memorials, centers of culture, and literacy at the time, are located near warm or mineral springs to which curing effects were attributed.

Records from the age of Turkish domination (15-19th century) mention warm baths in mineral spas. In addition, several places in Serbia have indicative Turkish word "ilidza" (spa) or "hamam" (bath) in the name [10].

Modern development of the resorts possessing thermal or mineral springs began between the two world wars and continued in the latter half of the century, with the construction of new or remodeling the existing infrastructure in most of the spa resorts.

A spa area is defined in respective regulations as an area of one or more natural healing factors that has standard establishment and facilities for their utilization. Natural healing factors are considered to be: thermal and mineral water, air, gas, and mineral mud of confirmed medicinal effect [11]. More than 30 locations in Serbia have thermal or thermomineral* sources and at least some of spa facilities for potential balneal use, 29 of which registered as spas with the Association of spas and air resorts of Serbia [12]. Medicinal and wellness spas are important segments in developing tourism of Serbia.

Basic properties of thermomineral waters used in 29 spas of Serbia are given in tab. 2.

Differences in the water discharges, temperature, reservoir lithology and TDS are noticeable. The table does not give other relevant information: geological (geothermal) structure, depth of the aquifers, specific chemical composition, which also indicate great diversity in the formation conditions. Characteristically, "pure forms" of the aquifer lithology and the geological structures are very difficult to recognize even after drilling. Interpretations of the thermomineral water formation are often hypothetical.

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* Thermomineral water is understood to be water characterized by elevated temperature, mineral salts and/or presence of specified chemical constituents that make it medical water, which is an attribute of waters in all spas of Serbia

Table 2. Properties of thermomineral waters in major spas in Serbia

No.	Spa name	Capture type	TDS [gl^{-1}]	Chemical type	T [°C]	Flow [ls^{-1}]	Capacity [MW$_t$]	Energy [TJ per year]
1	Kanjiža spa	Wells	1.6-4.3	HCO_3-Na	27-63	19	2.38	75.03
2	Junaković spa	Wells	5.8-6.6	Cl·HCO_3-Na	46-49	20	2.26	71.25
3	Bečej spa	Wells	4.0	Cl·HCO_3-Na	65	25	4.71	148.48
4	Vrdnik spa	Wells	1.9	HCO_3·SO_4-Mg, Ca	33	45	2.45	77.24
5	Selters spa	Wells	7.2	HCO_3, Cl-Na	32-60	20	2.09	65.89
6	Palanački Kiseljak	Wells	8	HCO_3, Cl-Na	50	4	0.50	15.76
7	Ljig Spa	Well	1.32	HCO_3-Na	33	4	0.22	6.94
8	Koviljača spa	Wells	1.42	HCO_3-Na, Ca, Mg	30	20	0.84	26.48
9	Bukovička spa	Well	4.32	HCO_3-Na	31-34	3	0.18	5.67
10	Gornja Trepča	Springs and wells	0.57	HCO_3-Mg, Ca	27-31	21	0.97	30.58
11	Ovčar spa	Springs and well	0.7	HCO_3-Ca, Mg	36-38	50	3.77	118.85
12	Vrnjačka spa	Springs and wells	2.9	HCO_3-Na	36	6	0.40	12.61
13	Mataruška spa	Wells	1.5	HCO_3-Na, Mg, Ca	25-51	72	6.02	189.78
14	Bogutovac spa	Well	0.50	HCO_3-Mg, Ca	25	10	0.21	6.62
15	Ribarska spa	Springs and wells	0.4	HCO_3,SO_4-Na	44	37	3.72	117.27
16	Brestovac spa	Springs and wells	0.71	SO_4-Na, Ca	20-41	7	0.44	13.87
17	Gamzigrad spa	Springs and well	0.65	HCO_3,Cl-Na	30-42	10	0.63	19.86
18	Soko spa	Springs and wells	0.55	HCO_3-Ca, Mg	22-46	25	2.09	65.89
19	Pribojska spa	Springs	0.4	HCO_3-Ca, Mg	36	70	4.69	147.85
20	Lukovska spa	Wells	1.9	HCO_3-Na, Mg	64-67	12	2.31	72.82
21	Niška spa	Springs	0.45	HCO_3-Ca	37	35	2.49	78.50
22	Jošanička spa	Springs	3.25	HCO_3, Cl-Na	50-77	19	3.58	112.86
23	Kuršumlija spa	Well	3.1	HCO_3-Na	64	16	2.95	93.00
24	Prolom spa	Well	0.22	HCO_3-Na	31	10	0.46	14.50
25	Sijarinska spa	Springs and wells	4,75	HCO_3-Na	61-76	36	7.53	237.38
26	Novopazarska spa	Springs	1.6	HCO_3-Na	51	5	0.65	20.49
27	Zvonačka spa	Spring	0.42	HCO_3-Ca	28	5	0.17	5.36
28	Vranjska spa	Springs and wells	1.4	HCO_3,SO_4-Na	63-95	80	19.08	601.49
29	Bujanovac spa	Wells	4.8	HCO_3-Na	42	7	0.64	20.18
Total:						693	78.40	2472.49

Total discharge of thermomineral water is around 700 l/s and the temperature range is from 25 to 96 °C.

All thermomineral waters used in balneal therapy are for bathing. Most spas have two or more springs or wells often different in mineral composition and/or temperature. Traditionally in some spas, less warm water from one source is used for drinking, and from the other for bathing.

Prospects of additional use of HGTE

HGTE is renewable energy and it could be defined, in respect to the most common technology of utilization as a local energy because it is used *in situ* or near the place of occurrence. A longer transport cools warm water, reduces its heating potential, and thus affects the energy efficiency effect. For this reason, central heating/cooling system, located always near the water-intake structure, is the practical, economical, and ecological model of an additional use of thermal water energy.

Table 3. Possible use of thermal waters in spa areas

Use	*T* [°C]
– Balneo, wellnes and sanitary use	
Balneotherapy	37-45
Swiming pools	22-30
Sanitary hot water	40-50
– Space heating	
High temperature systems (radiators)	65-80
Middle temperature systems (convectors & central air systems)	50-65
Low temperature systems (wall panels and floor heating)	30-50

Thermal water not used in balneal therapy or part of the therapy-used thermal water may be additionally, energy-efficiently used in almost each spa (tab. 3). In the cold season of the year, for heating baths, rooms, medical establishments, sport and recreation halls, hotel and service rooms, and for warm-water consumption. In the warm season, when tourist impact is the greatest, surplus thermal power may be diverted to expand the spa-and-wellness capacity: swimming pools, baths and massage pools. Another important aspect of the thermal water power utilization in spas in summertime is cooling the establishments, which requires a heat pump air-conditioning system.

Heat power/thermal capacity of the abstracted thermal water is calculated using the following equation [13]:

$$\text{TC [MW}_\text{t}\text{]} = \text{flow rate [kgs}^{-1}\text{]} \times \text{(inlet temperature [°C]} - \text{outlet temperature [°C])} \times 0.004184 \text{ [MW]} \quad (1)$$

where

- flow rate is the discharge of thermal water identical to the quantity in l/s given in tab. 2, and
- inlet temperature is the "water temperature" from tab. 2; and
- outlet temperature is the adopted value of 20 °C as the lowest outlet temperature of water used in swimming pools (tab. 3).

Total heat power of all waters (tab. 2) is 78.40 MW_t, in the range from 0.21 MW_t to 19.09 MW_t, with the highest power registered in Vranjska spa and the lowest in Bogutovačka Spa.

Total energy of all waters (tab. 2) is 2472 TJ per year and is calculated for each spa using the following equation [13]:

$$\text{Energy [TJ per year]} = \text{flow rate [kgs}^{-1}\text{]} \times \text{(inlet temperature [ºC]} - \text{outlet temperature [ºC])} \times 0.1319 \text{ [TJ]} \quad (2)$$

In view of the great variety of prospective HGTE uses, including other than those in table 3 (green-houses, fruit and vegetable drying, fish farming, snow melting, space heating supported by GHP, *etc*.), the obtained amounts of heat power as well as of energy are not accurate nor representative, only basic and illustrative information.

For additional utilization of the thermomineral water heat power the following should be taken into consideration.

(1) Exclusion or significant reduction of conventional fuel for heating water and the heating process will cut the costs; also exclusion or great reduction of noxious gas emission into the atmosphere to the benefit of the environment and a contribution to the tourist image and commercial rating of the spa.

The value of 2472 TJ per year (687 GWh) represents a remarkable saving potential, considering its equivalence with 59,000 t of crude oil, or 102,000 t of coal, or $81 \cdot 10^6$ m^3 of natural gas. Table 4 shows the respective amounts of greenhouse gases savings.

Table 4. Potential greenhouse gases savings

	Crude oil	Coal	Natural gas
CO_2	278,000 t	324,000 t	66,000 t
SO_x	1,840 t	2140 t	435 t
NO_x	525 t	615 t	125 t

(2) Like the other renewable energy sources, geothermal energy involves high investment costs and relatively low labor costs. With a conventional heating system, the cost of thermal energy is largely related to the price of fuel (coal, oil, gas), whereas the depreciation charges for the heat-producing plant are lower.

The basic cost items of a system using the heat energy of thermal water are the depreciation of thermal-water well and then of heat-producing plant and distribution pipes; cost of "the fuel", or thermal water, is far lower than the price of any conventional fuel. The financial aspect of HGTE-supported heating systems is even more favorable for the spas with developed intakes of thermal water, because the investment costs are excluded, and the depreciation charges for the existing water-abstraction structures and working expenses are met from the receipts for balneotherapy and from the lower-cost heating.

(3) Particularly advantageous are natural warm springs, with even lower working expenses unburdened with the power cost for pumping thermal groundwater at the surface and with depreciation charges for the intake structure.

(4) A principal characteristic of thermal water as a source of heat power is the constancy of its temperature and discharge in a well or natural spring. It makes a difference and provisional disadvantage in relation to the heat distribution system using conventional fuel, with water heating to a desired level that depends on how high is the external temperature. The region where the spas are located has three seasonal changes to which the HGTE demand is related:
   - difference in the heating/cooling demand over the year,
   - seasonal changes in number of guests, which directly influences the intensity of all modes of HGTE uses, and

– use of outdoor bath facilities is limited to the warm season.

Balneal and heat-power uses of the available thermal water resource should be well coordinated in a combined system with the view to:

– heat power potential of the available groundwater resource, and
– present and/or planned spa infrastructure and seasonal fluctuation in the use of thermal water of different temperature (tab. 3), including cascade (re)use of the same water quantity.

(5) The use of a heat-exchange unit is a general option for utilization of the thermal water heat energy. In such a system, a part of the geothermal heat-energy of groundwater is transferred in an exchange substation to the fluid heating the indoor space. Thermal water of insufficiently high temperature is a limitation for any type of passive heat exchanger to cover the peaks of low external temperatures in a high or middle temperature heating system (tab. 3). The system must include a unit for additional water heating by conventional fuel.

A GHP generally supports efficient heat energy manipulation for heating/cooling space over most of the year and optimum utilization of lower temperature thermal water. Optimum utilization means utilization of most of HGTE for the longest period of the year in cascaded use for different purposes that require water of different temperature ranges (tab. 3). A central system of indoor air-conditioning includes GHP that function as cooling units during the summer season at both energy and economic benefit.

Upgrade of 43 MW_t of heat power would be achieved potentially by cascade (re)use of all 693 l/s of spa waters in GHP processing, with inlet temp of 20 ºC and outlet temp of 5 ºC.

(6) Excessive TDS in water occurs in a system, in which case a water-treatment unit or a double (one standby for cleaning/repair of the other) heat exchanger installation is necessary.

(7) Thermal water used for heating will not be suitable for balneal therapy, because its treatment is affecting the quality that make it medicinal water. On the other hand, partial utilization of the thermal water energy is a loss of energy, and disposal of warm water into the environment is a potential ecological impact. A feasible option is to direct unused thermal water to swimming pools, or supported by heat-exchange pumps to recycle it for heating some other space.

Each spa area in Serbia is specific in respect to the available water resource and temperature and to the existing and planned infrastructures. For this reason, each system of the combined balneal therapy and heating/cooling space should be conceived to comply with the two purposes. On the other hand, the infrastructure should be planned to match the character of HGTE resource and the technology of its best utilization.

Investments in the adjustment or replacement of the present conventional heating systems will be recovered relatively soon, because of the reduced use of conventional fuel and because the HGTE resource is available without necessary drilling or development of thermal water captures. Moreover, installation of an environment-friendly and energy-efficient heating system will be supported by the state and/or local administration.

Examples of additional hydrogeothermal energy utilization

Additional use of thermal water heat energy is practiced in several spa resorts of Serbia: Vranjska, Sijarinska, Kuršumlija, Lukovska, Ribarska, Selters, Niška, and Prolom.

Thermal water has been used in Vranjska spa from the 1970s for heating the therapy centre, hotel, green-house over six hectares, poultry farm, and a textile plant. The water from 65 to 96 ºC temperature is used at the rate of 32 l/s, [8]. The temperature in the primary reservoir is 130-140 °C [14].

Thermomineral water of 75 ºC is used at the rate of 5-6 l/s in Sijarinska spa for heating the Geyser hotel. A part of the hydrogeothermal energy exchanged in the substation is given over to the hotel building, where heating is necessary only in extremely cold days. Water temperature is 37 ºC at the outlet [15].

Kuršumlija spa uses 20 l/s of thermal water for heating the therapy centre and swimming pool. Outlet water temperature is about 25 ºC [8].

Niška spa has installed a heating system with heat pump units of heat power 6 MWt in the therapy centre. The system uses recycled thermal water of 25 ºC from the balneal centre [16].

The Radan hotel in Prolom spa is heated by water of 30 ºC supported by heat pumps [7].

Two hotels in Lukovska spa is heated by water of 64-67 ºC.

Heat energy of thermomineral water in some spas is being used or is planned to use for some other purposes, such as heating the Palanački kiseljak water-bottling plant [17], green-house heating in Jošanička spa [18] fruit and vegetable dehydration plant in Sijarinska spa [15], as well as the mentioned heating of industrial and farm buildings in Vranjska spa.

Conclusions

The balneological use of thermomineral water has a long tradition in Serbia. Balneal infrastructure (pools, baths, and medical and spa wellness equipment, accommodation facilities) has been renewed in the last thirty years, continuously tending to update and improve the offer.

Thermal waters in the spa areas of Serbia are not fully used in the developing tourism. The available resources of thermal waters from 25 to 96 °C temperature in the described 29 spas total some 700 l/s, or heat power of 78.40 MW_t. Further 43 MW_t of heat power would be achieved by GHP reuse of spa waters. Balneological or additional use of surplus heat energy from thermomineral waters are below the full capacity of the available resource in most of the spa areas.

The best additional use of water heat energy is heating the balneal establishments located near the thermal springs/wells during the cold period of the year, because it reduces the heating costs and improves the ecological-health image and tourist-market rating of a spa. In the summer, surplus heat energy may be diverted to expand the spa wellness capacity and to indoor cooling.

Each spa area is specific where the available supply and temperature of water, and the existing and planned infrastructure are concerned, so that a combined balneal and indoor conditioning system should be conceived to mach the two uses. Planned infrastructure also should be in line with the properties of HGTE resources as well as with technology for an optimal use of thermal water of different temperature, including cascade use.

Prospective legislative modifications in Serbia concerning concessions for exploitation of thermomineral resources in spas will make room for new investments aimed at grater and more efficient use of thermal water both in spa wellness and additional uses.

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