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Heat potential of the Upper Jurassic-Lower Cretaceous aquifer in Central Northern Bulgaria: conditions and prospective use

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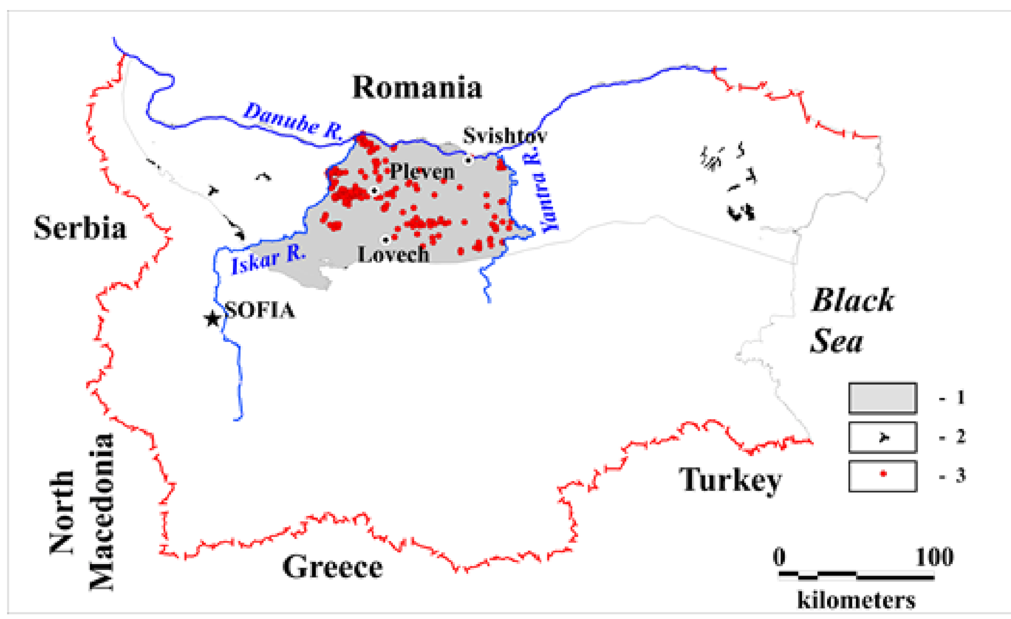
Introduction

In recent years, the use of renewable energy, including geothermal energy, has been extensively increasing globally in accordance with the documents adopted by the global forums on climate and sustainable development. The geological setting of Bulgaria provides conditions for the formation of thermal waters that could be used as energy sources . The hydrothermal resources have been evaluated to 9957 TJ/a and they are not being sufficiently utilized. Considering that the temperature of most thermal waters in Bulgaria are up to 100ºC, so far these resources have not been used for electricity production. The aim of the present study is to evaluate the potential for heat extraction and the possibility for heat production from the thermal reservoirs formed in the deep parts of artesian aquifers.

FORMATION OF THERMAL WATERS IN THE STUDY AREA



Map of the studied region: 1 – area of the Upper Jurassic-Lower Cretaceous aquifer; 2 – aquifer outcrops; 3 – boreholes.

Geologically, Northern Bulgaria is within the expanse of a platform structure, which forms a large and complex artesian basin. It is set up by deep aquifers separated by aquitards. In this sequence, the Upper Jurassic-Lower Cretaceous aquifer has the largest area, greatest thickness and it is the most water abundant. This aquifer has limited outcrops in its southern part and within the area of the so-called North Bulgarian Uplift in Northeastern Bulgaria. From there, it gradually dips to over 4000 m depth in Northwestern Bulgaria. The main groundwater reservoir is a carbonate complex of limestone and dolomite, whose high water permeability and high yield are the result of active palaeokarst processes . The thickness of the aquifer is in the range of approximately 700 m to 1500 m, except for the outcrop zones in its southern part, where it abruptly decreases to about 100-200 m due to facies transition. The hydrodynamic parameters vary within a very broad range, which results in quite specific conditions for heat accumulation and potential for extraction in the different parts of this aquifer. High transmissivity is typical for its eastern part, where the highest recorded values are above 3000 m^2/d.

The transmissivity decreases to approximately 40 m^2/d to the west and southwest. As a rule, high transmissivity and yield correlate to lower geothermal gradient. Previous studies identified low values of the geothermal gradient within the aquifer – between 1°C/100m and 2.5°C/100m, which is related to its relatively high yield. The highest values are found in the deep southwestern part of the aquifer, characterized by the least degree of karstification and where convective heat transfer is inhibited. With the top of the aquifer dipping from east to west/southwest, the groundwater temperature increases - from around 40ºC and less, in the near surface eastern part of the study area, to above 100ºC in its southwestern part, at depths below 3000 m.

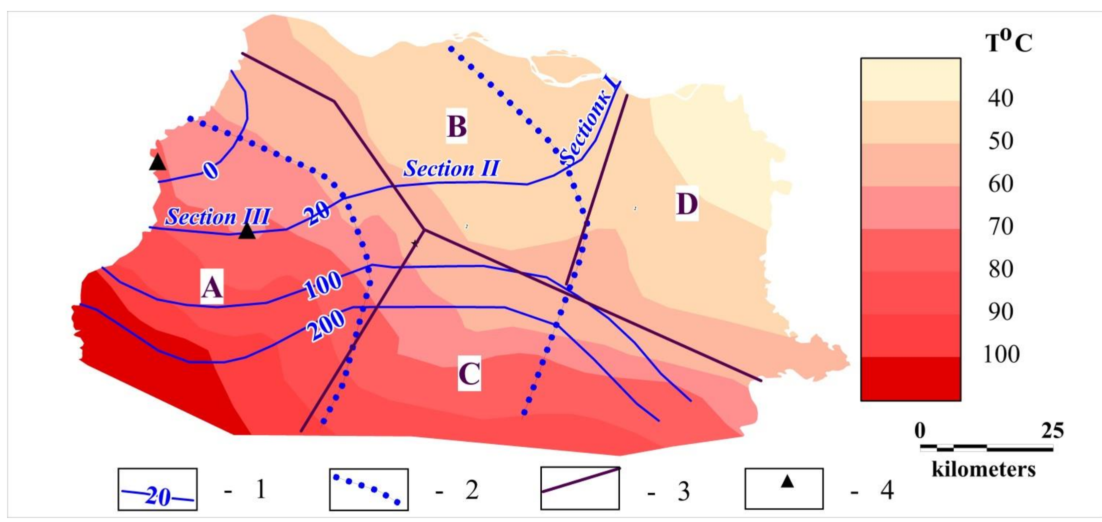
In the confined eastern part of the aquifer, there are chloride-sulphate-sodium-calcium and chloride-sulphate-sodium types of water with total mineralization between 1.55 g/l and 10 g/l. With increasing depth, the water type changes to sodium-chloride, and the mineralization increases to above 20 g/l, which is the reason for considerable deposition of minerals in the course of thermal water abstraction.

METHODS

The study was performed in the following sequence: (i) evaluation of the static groundwater reserves in the thermal water reservoir; (ii) determination of the regional density-dependent groundwater flow; (iii) drawing a groundwater temperature map on a regional scale; (iv) differentiating sections and blocks of relatively homogeneous properties; (v) calculation of the renewable groundwater resources and heat energy reserves by sections; (vi) evaluation of the regional reserves of heat energy in the blocks for the abstraction by reinjection systems; (vii) economic valuation of reserves by blocks and by sectors.

Regional heat reserves extractable by reinjection systems were evaluated by applying an innovative method that was developed and approbated for the overall evaluation of the heat reserves in Bulgaria by a team of the Geological Institute at the Bulgarian Academy of Sciences. In summary, the approach is as follows: the thermal water reservoir is divided into blocks with average values for temperature θ, transmissivity T, aquifer thickness m, and total groundwater resources Qsum. The area of each block is covered by well doublets with equal circulation rates Q_D, whereas the abstraction and reinjection wells are being distributed in a checkered pattern, spaced at equal distances D. The total groundwater resources in each block is calculated by summing up its renewable groundwater resources and static groundwater resources. The yield of each well doublet is $Q_D = Q_{sum}/n$, where n is number of doublets in a block.

RESULTS AND DISCUSSION



Distribution of the density-dependent groundwater flow. Map of groundwater temperature. Sections and blocks for evaluating the heat potential of the Upper Jurassic-Lower Cretaceous aquifer: 1 – equipotential lines; 2 – section boundary; 3 – block boundary; 4 - geothermal power plant.

The total volume of the Upper Jurassic-Lower Cretaceous aquifer in the study area is 8139x10^9 m^3, and the mean storage coefficient is 0.05. The calculation is based on the thickness contour map and data from numerous groundwater flow investigations. Considering the above values, the static groundwater reserves of the geothermal reservoir were estimate to 406x10^9 m^3. These water volumes are characterized by temperatures and mineralization increasing with depth. Water with temperature in the range 50-80°C forms the main portion, approximately 60%; while water with temperature below 50°C amounts to approximately 30% of the available water reserves

There could be distinguished three sections in the area: I, II, and III, as well as four blocks: A, B, C, and D. The groundwater resources were calculated for average width of the flow across the 20 m equipotential line, and the heat reserves – for a temperature drop to 15°C.

Table 1. Average values of temperature, transmissivity, and hydraulic gradient by sections. Renewable water resources (Q)

Section	Temperature	Transmis-sivity	Hydraulic gradient	Renewable resources
	°C	m^2/d	-	L/s
I	50	1500	0.0003	110
II	55	140	0.003	530
III	65	40	0.4	740
			Σ Q	1380

Table 2. Average values of temperature and aquifer thickness by blocks. Individual and total yield in well doublets

Block	Temperature	Thickness	Individual yield	Total yield
	°C	m	L/s	L/s
A	65	900	7	6300
B	50	700	20	25000
C	70	1100	10	8000
D	45	800	30	22500

Table 3. Heat reserves in the Upper Jurassic-Lower Cretaceous aquifer (annual)

Section	Thermal energy	Equivalent fuel	Price*
	TJ	t	USD
I	508	12136	728160
II	2796	66794	4007640
III	4880	116579	6994740
Total	8184	195509	11730540

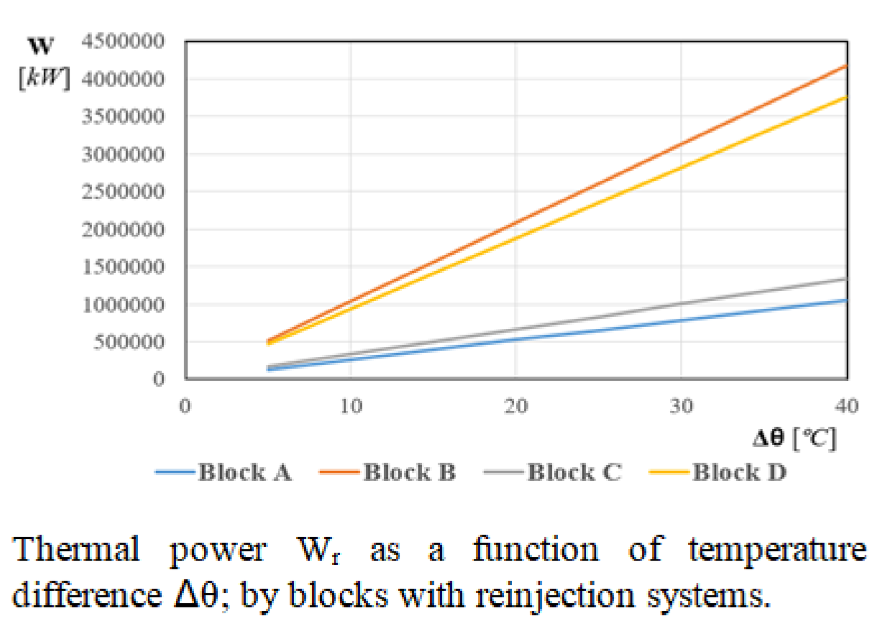
* At 60$/t mean market price of crude oil for the 1st quarter of 2021

The thermal power extractable by reinjection system $Q_{\theta r}$ was calculated by assuming that the defined well doublets in the four blocks operate at yields Q_D and Q_{sum} (Table 2). The total number of doublets n is 3700, which corresponds to 900, 1250, 800, and 750 for the individual blocks A, B, C, and D. The projected depressions in the abstraction wells are between 5 m and 30 m and the transit time for breakthrough of re-injected water vary between 50 and 350 years. For each block, the $Q_{\theta r}$ values (per annum) were calculated at 15°C temperature drop in reinjection systems and are listed in Table 4, whereas the established relationships between thermal power W_r and temperature difference Δθ

Table 4. Thermal energy extractable by reinjection systems by well doublets (per annum)

Block	Thermal energy	Equivalent fuel	Price*
	TJ	t	USD
A	41543	992427	59545620
B	115399	2756785	165407100
C	58029	1386264	83175840
D	89022	2126660	127599600
Total	303993	7262136	435728160

* At 60$/t mean market price of crude oil for the 1st quarter of 2021



Thermal power W_r as a function of temperature difference Δθ; by blocks with reinjection systems.

CONCLUSION

Based on the results of the study, the following conclusions can be made about the potential heat extraction from the Upper Jurassic-Lower Cretaceous aquifer in the considered region:

(i) The heat resources are estimated to 8184 TJ (per annum). Converted to equivalent fuel this makes 195509 t oil, or approximately 11.73 million USD.

(ii) The total heat extractable by reinjection systems $Q_{\theta r}$, amounts to 303993 TJ/a, which expressed as equivalent fuel equates 7262136 t oil for approximately 435.7 million USD.