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Original Research Article

ASSESSMENT OF THE THERMAL POWER OF GROUNDWATER INTAKES IN THE KIELCE DISTRICT

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Abstract

The purpose of the article was to estimate the thermal power of groundwater intakes of the Kielce district within the sheets of hydrogeological maps with the serial numbers MHP 813-817, MHP 850-851, and to indicate in this area prospective areas for the development of low-temperature geothermal energy supported by water/water heat pumps. Based on the calculations on the basis of 147 groundwater intakes, it was determined that the estimated values of thermal power resources are in the range of 3.47 kW to 5757.34 kW. The created map of the low-temperature geothermal potential for groundwater intakes indicates the towns of Bodzentyn, Morawica and the villages of Piekoszów, Wolica and the area around the village of Górno as prospective areas.

Keywords: low-temperature geothermal, RES, thermal power, energy efficiency index, groundwater intake, heat pumps

1. INTRODUCTION

Geothermal energy is a renewable resource due to the inexhaustible source that is the Earth's interior. Including energy from soil-source heat pumps, installed geothermal capacity worldwide has increased by 52 % in the past five years to

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107.727 GW [1]. It is estimated that 25 % of the European Union's population lives in areas rich in geothermal resources, thus installations using the Earth's heat are likely to make a significant contribution to covering energy demand [2]. There are different ways to use geothermal energy. Installations extracting energy up to 400 meters deep are referred to as shallow geothermal. Depending on the energy source medium, there are closed systems based on collecting heat from the soil using flat collectors or using vertical heat probes [3]. A developing technology based on the extraction of energy from the soil is the use of energy thermopiles or thermally active systems. Foundations used as a heat receiver can provide an alternative to conventional closed systems. Open systems that draw energy from groundwater also play an important role in shallow geothermal. The most common solution is the use of a supply well and an absorption well. The open system solution is characterized by a more efficient heat source compared to soil solutions. The reason for this is the thermal stability of groundwater sources, resulting from the lack of influence of seasonal temperature changes as in the case of soil [4].

The use of the low-temperature sources can bring real environmental and economic benefits especially in renewable energy, but the individual solutions using lower heat sources have significant barriers limiting their development [5-6]. In the case of the low-temperature geothermal systems supported by heat pumps, there are economic, informational and legislative barriers. The requirement to comply with a number of procedures included in the geological and mining law, water law, environmental law and building code is a major difficulty already at the stage of selecting a lower heat source for heat pump-based installations [5]. Installations that obtain heat directly from the soil require significantly less procedures, making them more interesting to potential investors. Information and education barriers play an important role regardless of the choice of heat source. Commonly available information is most often of an advertising nature, with no description of the advantages and disadvantages of the various available solutions and requirements. This is particularly evident in the technology of water-to-water heat pumps [4-5]. The initial barrier facing anyone interested in heat pump technology is cost efficiency. Depending on the bottom source used, the cost of installation can be as high as twice that of conventional solid fuel boilers. In addition to the cost of the pump itself, drilling work and geological surveys are necessary. In the case of varying geological structure, drilling work can consume 50 % of the total investment cost [7]. The low-temperature geothermal research and development community notes the lack of cooperation between drilling contractors and PIG in sharing geological information, which significantly delays the mapping of low-temperature geothermal potential [8].

The available maps of low-temperature geothermal potential cover only a part of the Polish area and are mainly considered in terms of installations that obtain heat directly from the soil [4]. They show the physical-thermal properties of rocks, less often of groundwater. In addition, they are made at large scales (>1:50000), which, with varying hydrogeological conditions, makes local interpretation difficult. As a result, an educational barrier and relatively little promotion of low-temperature geothermal installations supported by water-to-water heat pumps is felt. The varied geological structure and hydrogeological conditions of Kielce district limit the development of investments in low temperature geothermal using water-to-water pumps [9]. The authors did not find a paper evaluating the potential of Kielce District's groundwater intakes for heating purposes. One of the main criteria for the possibility of using groundwater for district heating is the efficiency of the intake, thus, analyzing archival materials, the area of Kielce district seems promising for this type of investition.

In the article, the authors estimated the thermal power of 147 groundwater intakes of Kielce District within hydrogeological map sheets MHP 813−817, MHP 850−851, and identified prospective areas for the development of low-temperature geothermal supported by water-to-water heat pumps. The collected data can be used as a tool to promote RES development in Kielce District, reducing low emissions and resulting in sustainable development.

2. CHARACTERISTICS OF THE STUDY AREA

2.1. Location

Kielce District has an area of 2246 km^2 and is located in the central part of Świętokrzyskie Voivodeship. The district consists of 19 communes (Fig.1). There are catchments of the rivers Nida, Kamienna, Pilica, Staszowska and Czarna. There are also 14 water reservoirs that perform recreational and retention functions. The area is rich in mineral resources. There are 169 mineral deposits, with limestone, dolomite, marl and sandstone dominating. The study area also contains 7 landscape parks, 11 protected landscape areas, 29 nature reserves, 5 natural and landscape complexes, 109 natural monuments and 15 Natura 2000 areas [10-11].

Fig.1. Communities of Kielce District *(Wikipedia, CC 4.0)*

The study area was most of Kielce District, which is included on serial hydrogeological map sheets numbered MHP (MHP 813−817; MHP 850−851) (Fig. 2).

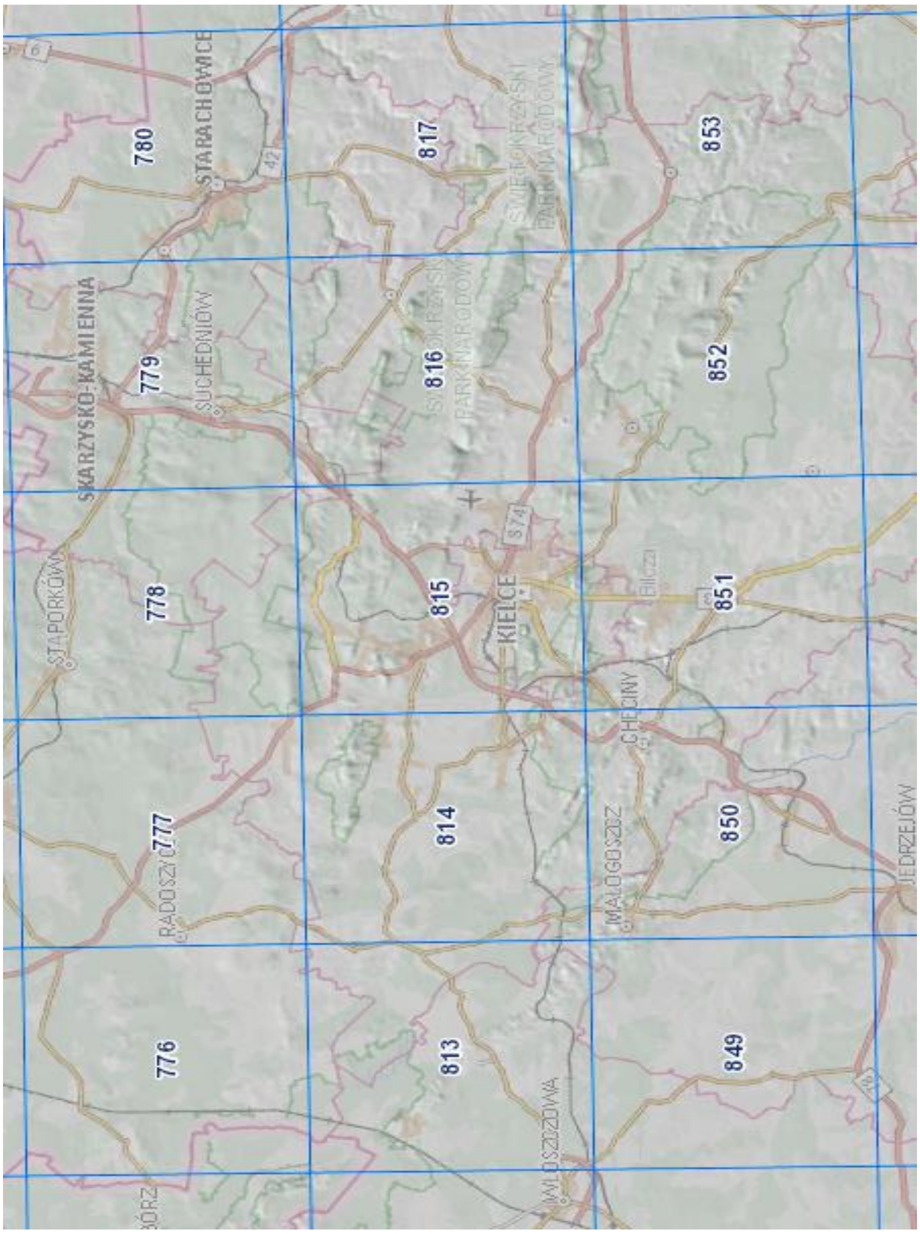


Fig. 2. The study area shown in terms of hydrogeological map sheets [14]

2.2. Geological conditions

The area of Świętokrzyskie Voivodeship, within which Kielce District is located, is unique in Europe in terms of geology. Three geological units contact each other within the province. One can distinguish between the Precambrian East European craton, the Paleozoic West European platform, and the Alpine rock mass and sinkhole zones. All three areas are characterized by a different geological structure. Rocks 500 million years old alternate with relatively young rocks several million years old from the rock mass and alpine sinkhole zones (Fig. 3) [12-13].

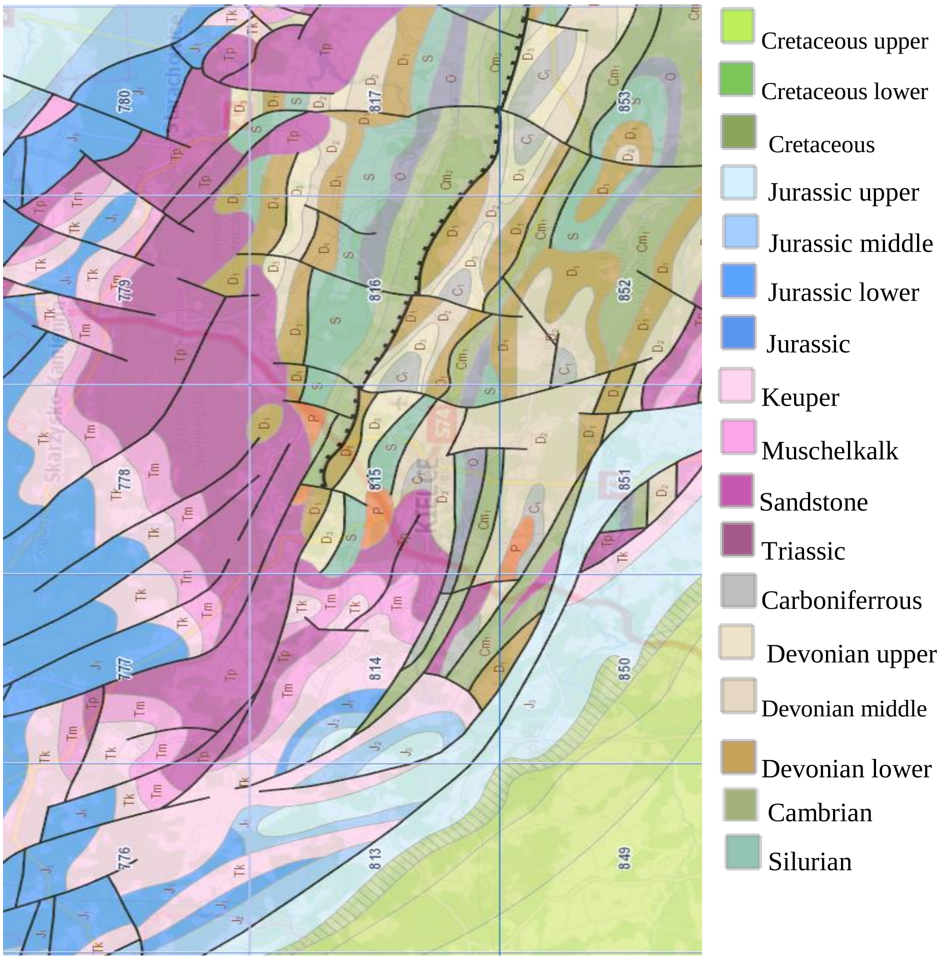
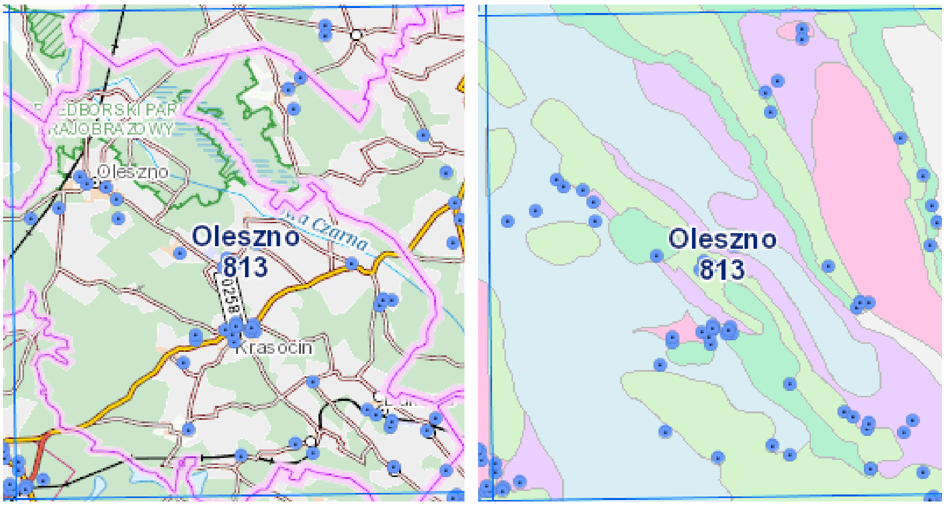


Fig. 3. Depth cartography of the Kielce district area [14]

2.3. Hydrogeological conditions

The western side of the Kielce District has a sheet named „Oleszno 813" (Fig. 4).

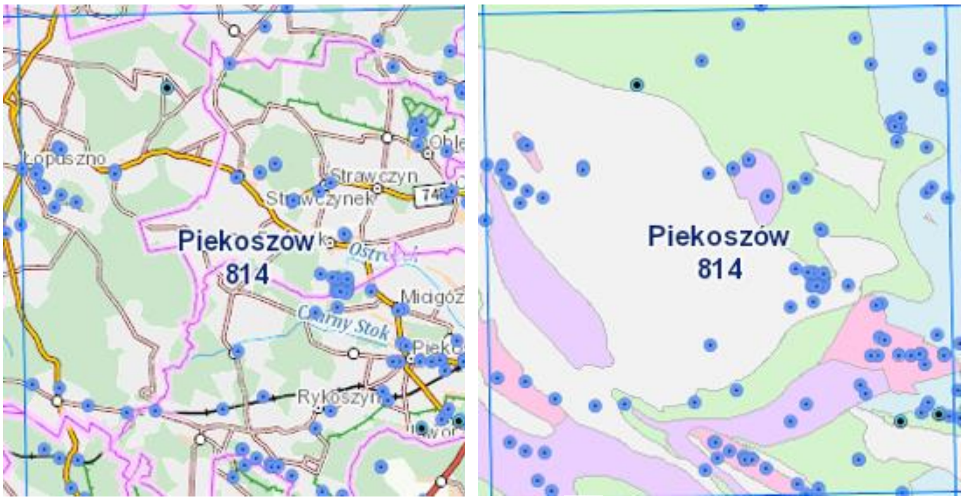


The potential capacity of a drilled well [m³/h] >70; 70-50; 50-30; 30-10; <10; groundwater intake.

Fig. 4. Potential capacity of wells on the sheet „Oleszno 813" [15]

Seven potential capacities of drilled wells can be identified here. For the western part of Kielce District, four main capacities can be identified, and for the most part this is the most capacitated area (70-120 m^3/h) [16]. The areas established and approved for municipal needs total 656.2 m^3/h, the total water intake is estimated at 30.3 m^3/h, which is 5 % of the exploitable supplies. The demand for industrial purposes in the presented district is much higher. The total amount of water used by companies is about 183.5 m^3/h, in some cases the intake is up to 50% of the exploitation supplies of the intake point. The supply of aquifers is the result of direct infiltration of rainwater, but it can also take place indirectly through Quaternary sediments of varying thickness. Groundwater reservoirs that can be used include Quaternary and Mesozoic formations, which consist of the main Jurassic and Triassic aquifers. The water table of the Upper Jurassic aquifer is formed at ranges from 280 m above sea level to 220 m above sea level [16-18].

The west-central part of the Kielce district is covered by the sheet „Piekoszów 814" (Fig. 5).

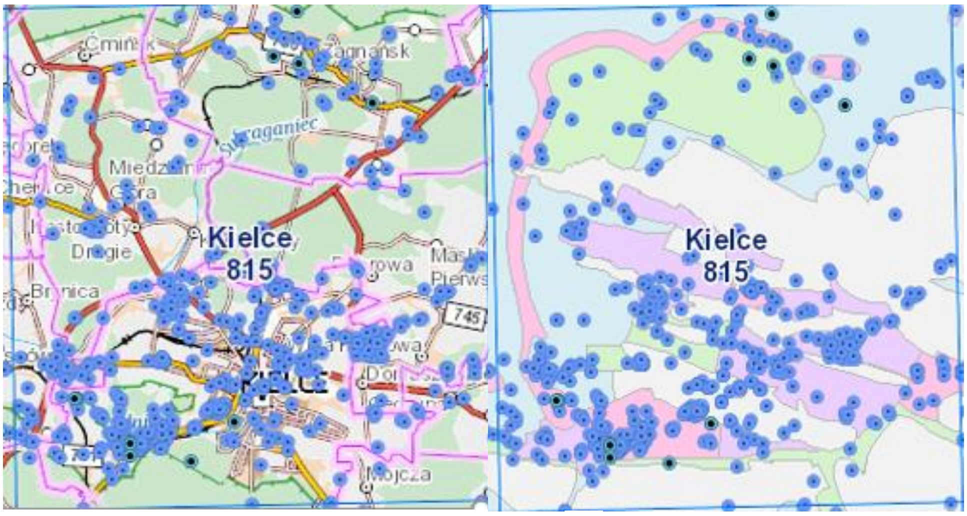


The potential capacity of a drilled well [m^3/h] >70; 70-50; 50-30; 30-10; <10; groundwater intake.

Fig. 5. Potential capacity of wells on the sheet „Piekoszów 814" [15]

Six aquifers can be identified in the sheet area. The Lower Triassic (T_1), Middle Devonian (D_2), Upper Permian (P_3), Middle Triassic (T_2), and Upper and Middle Jurassic horizons have the highest groundwater potential. The total area of all the main usable horizons is 196 km^2. The remaining 40 % of the area is without prospective usable horizons. The groundwater table is described as free, and occurs to a depth of 15 meters. Greater depths occur only locally most often on the tops of hills. It is conventionally assumed that the level of active groundwater exchange stops at 150 m below soil level. It is estimated that 70 % of groundwater supplies are renewable deposits. They range from 150 to 210 m^3/24 h, except for a small area located in the southern part of the Kielce syncline. The disposable resources of this area are 347 m^3/24 h [19]. Within the sheet, three groundwater reservoirs are identified that require special protection: GZWP 414 Zagnańsk, GZWP 416 Małogoszcz and GZWP 417 Kielce. The described area is characterized by high permeability, in many places aquifers are exposed even directly on the ground surface. Poor isolation occurs in the area covering the eastern part of the sheet, specifically in the fossil valley of the Bobrza River. Few industrial plants are potential pollution , the two largest being the Devonian limestone quarry "Ostrówka" in Miedzianka, and the Horticultural Farm in Piekoszow. Attention should also be paid to the municipal landfill in Promnik. It is located on the boundary of the usable Middle Triassic horizon and non-aquiferous Upper Triassic formations, the landfill site has periodic, seepage which causes local groundwater contamination. Surrounding villages that do not have a sewer connection may also be foci of pollution [19].

The central part of the study area, i.e., the "Kielce 815" sheet (Fig. 6), is characterized by the fragmentation of hydrogeological units due to the complex geological structure.

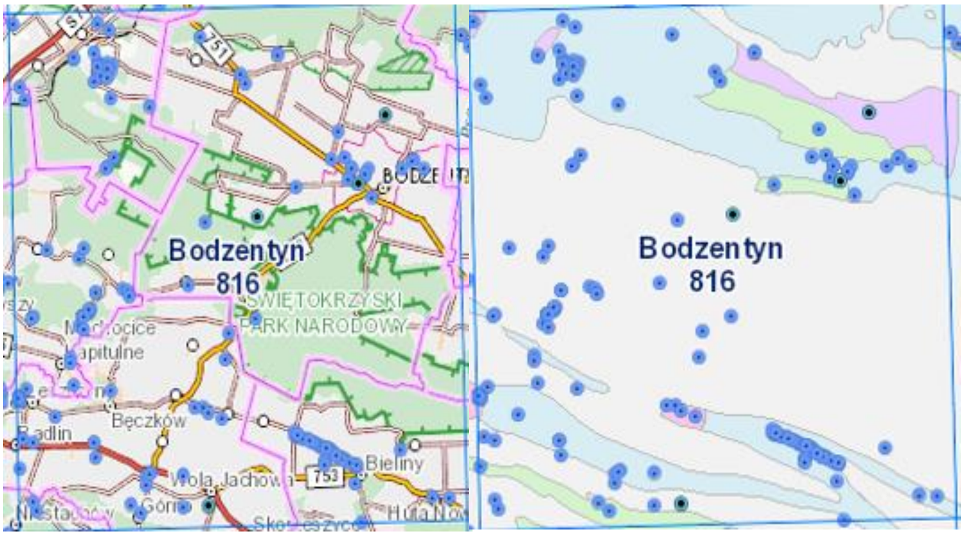


The potential capacity of a drilled well [m^3/h] >70; 70-50; 50-30; 30-10; <10; • groundwater intake.

Fig. 6. Potential capacity of wells on the sheet „Kielce 815" [15]

Within the boundaries of the area in discussion, 16 units were separated, this is due to limited hydraulic contact. The groundwater table is defined as free. The pressure table is found in Quaternary formations, where there are silts and stagnant clays or semi-permeable clays. The main aquifers are located at a depth of 2 to 105 meters. This is a consequence of the morphology of the area and the thickness of the overlying Quaternary sediments [20-21].

The "Bodzentyn 816" sheet has negligible usable groundwater supplies (Fig.7).

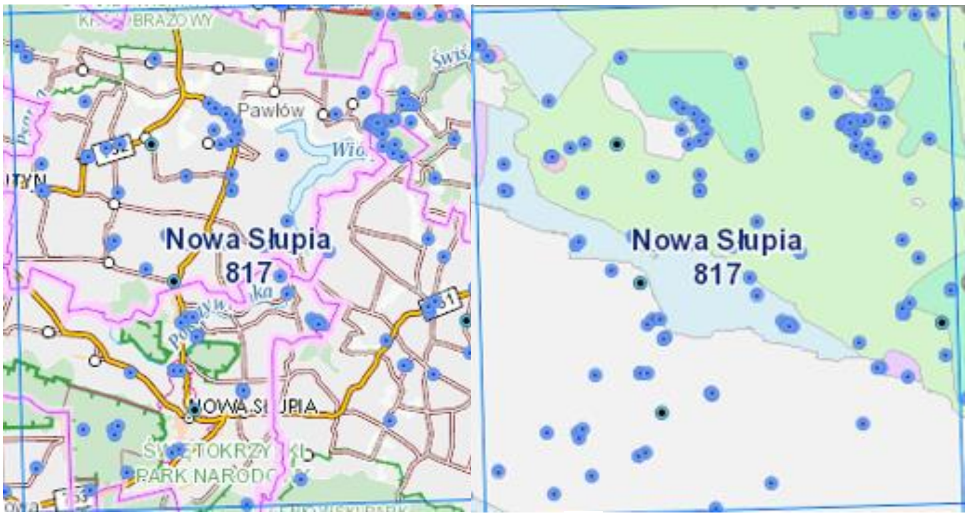


The potential capacity of a drilled well [m^3/h] >70; 70-50; 50-30; 30-10; <10; groundwater intake.

Fig.7. Potential capacity of wells on the sheet „Bodzentyn 816” [15]

They are found only in the Middle Devonian, Upper Devonian, Triassic and Permian formations. The rocks of the older Paleozoic are non-water-bearing. Two modules of disposable resources can be identified. For Triassic and Permian formations, the renewable resources are 60 %. However, for the Devonian, this ratio is 70 %. The depth of active groundwater circulation is about 150 m. As in previous sheets, the water table is free in character with local exclusion in areas of poorly permeable Quaternary sediments. The varying degree of cracking and karstification causes significant differences in the capacity obtained from an individual well. The capacity can vary from 0.5 m^3/h to 119 m^3/h [22].

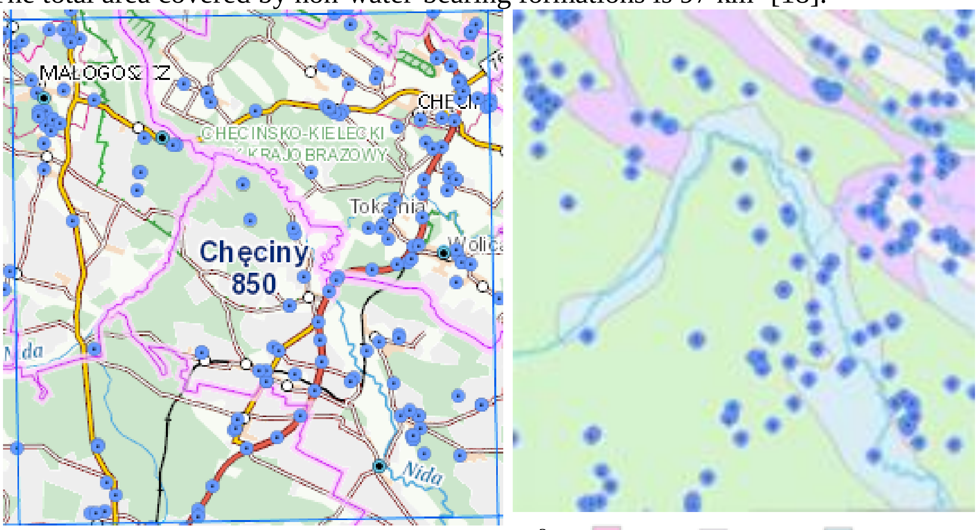
The eastern part of Kielce District, sheet "Nowa Słupia 817", is characterized by low aquifers from 10 to 30 m3/h with minor exceptions, where the potential capacity of a well can be from 70 to even 120 m^3/h (Fig. 8). The usable aquifer accounts for about 60 % of the sheet area (196.68 km^2). The usable aquifers are defined as Devonian, Triassic and Quaternary [23].



The potential capacity of a drilled well [m^3/h] >70; 70-50; 50-30; 30-10; <10; groundwater intake.

Fig.8. Potential capacity of wells on the sheet „Nowa Słupia 817” [15]

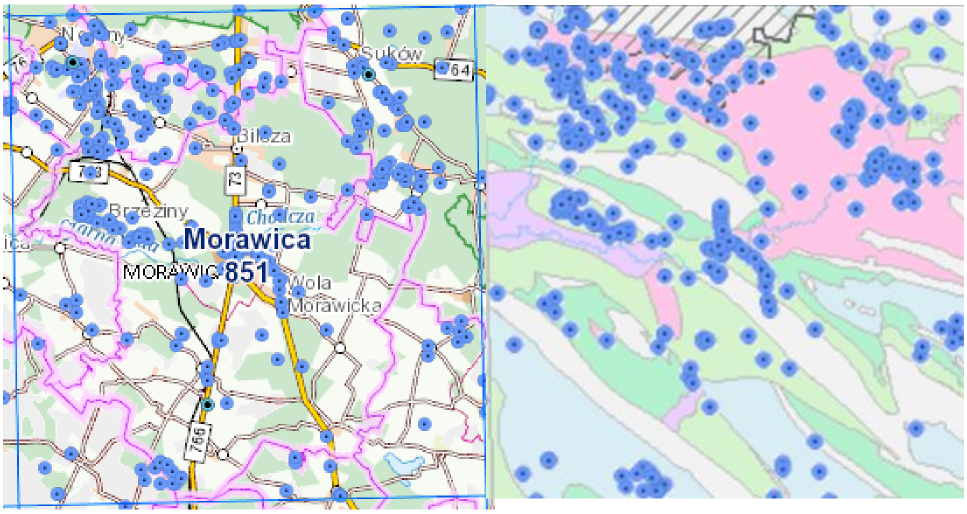
Sheet MHP-850 (Fig. 9). The usable Quaternary horizon occurs locally in the valleys of the Bobrza River and the Black Nida, Biała Nida and Nida rivers. Renewable resources are estimated to amount to 60–75 % of the disposable resources. As many as 57 hydrogeological units have been separated in the area. The total area covered by non-water-bearing formations is 97 km^2 [18].



The potential capacity of a drilled well [m^3/h] >70; 70-50; 50-30; 30-10; <10; groundwater intake.

Fig. 9. Potential capacity of wells on the sheet „Chęciny 850" [15]

In the area of the "Morawica 851" sheet, depending on the type of aquifer, the capacity varies and ranges from 10 to as much as 120 m^3/h (Fig. 10).



The potential capacity of a drilled well [m^3/h] >70; 70-50; 50-30; 30-10; <10; groundwater intake.

Fig.10. Potential capacity of wells on the sheet „Morawica 851"[15]

There are two fractured-karst major groundwater reservoirs in the sheet. In the southwestern part of the sheet is a part of the Upper Jurassic GZWP No. 416 Małogoszcz. The SCI is located adjacent to the fractured reservoir in Upper Cretaceous formations No. 408 Miechowska Trough. The northern part of the sheet includes the GZWP No. 418 Gałęzice-Bolechowice-Borków covering Middle and Upper Devonian formations [17].

3. METHODOLOGY FOR ESTIMATING THE THERMAL POWER OF INTAKES

Using the information contained in the database of the Polish Geological Institute - National Research Institute (PIG-PIB) and empirical formulas, the thermal power of groundwater intakes can be estimated. The basic data used to determine whether a given intake can be used for heating purposes are: the capacity of the intake, the height above sea level of the borehole, the value of the geothermal stage, determining how deep the zone of constant temperature is in the well, the location of the filter for determining the depth of water intake, the average annual air temperature in the area. Well users or contractors do not need to provide the temperature of the water in the well, so it is necessary to calculate the theoretical temperature using a formula (3.1) [24-26]:

$$T = t_a + A + \frac{H - h}{g} \tag{3.1}$$

where:
T – temperature of water at depth H [°C],
t_a – average annual air temperature in the area [°C],
A – constant depending on the height above sea level [°C],
H – depth of water [m],
h – depth of the constant temperature zone [m],
g – geothermal degree [m].

The average annual temperature in Kielce District was determined based on data from the Institute of Meterology and Water Management. In 2020, it was 9.8 °C [27]. The dependent constant 'A' was determined based on the height above sea level of the individual intakes (Table 1). The range of the constant is: 0.89 – 0.96 m.

Table 1. Constant ‘A’ depending on the height above sea level [25]

Height above sea level	0	500	1000	2000	2500
A	0.8	1	1.3	2.3	3

The depth of water was determined based on the hydrogeological profiles of the boreholes. The depth of the constant-temperature zone was assumed as 18 meters based on literature data [25].
The geothermal degree is most influenced by the thermal conductivity of the rocks, the relief of the land surface, the location of radioactive, geochemical and volcanic processes. It is assumed that the temperature increase at 1 m depth is 0.03 °C. The value of the geothermal degree has been set at 30.3 m [17].

After determining how much temperature is from the depth of water intake, the amount of power that can be obtained from a single intake can be calculated using the formula (3.2) [24, 26]:

$$Q = Q_w \cdot \frac{1}{3600} \cdot 1000 \frac{kg}{m^3} \cdot 4.19(T_w - T_{cw}) \tag{3.2}$$

gdzie:
Q– heat capacity of the hole [kW],
Q_w – intake capacity [m^3/h] - based on data from the National Geological Institute,
T_w – temperature of the water [°C],
T_{cw} – temperature of the cooled water [°C].

When using low-temperature systems based on heat pumps, it is useful to know the coefficient of efficiency of the heat pump. The higher it is, the better the conditions for the operation of the pump. The effect on the value of the coefficient depends on the temperatures of the lower and upper heat source. Using a correction factor of 0.5, the calculation cycle can be carried out according to the following formula [28]:

$$COP_T = 0.5 \cdot \frac{Tu}{T_u - T_l} \quad (3.3)$$

COP_T – adjusted efficiency ratio,
T_l – temperature of the lower source (water) [K],
T_u – temperature of the upper source (water) [K].

Based on the analysis of the thermal power of the hydrogeological boreholes, it is possible to make a preliminary assessment of the conditions in the area and to identify prospective areas for the development of low-temperature geothermal energy supported by water-to-water pumps within the investment area.

4. THE POTENTIAL OF SHALLOW GROUNDWATER FOR HEATING PURPOSES

The heat potential was determined based on an analysis of archival materials available on PIG-PIB 's website and on their calculation of the heat capacity of 147 groundwater intakes in Kielce District.

4.1. Potential assessment based on review of archival geological materials

The most prospective complexes in Kielce District are the Upper and Middle Devonian formations. The use of low-temperature deposits is possible with the use of water-to-water heat pumps. Water accumulation is most likely to be found in areas with synclinal and trough-like structures, where folded and trough-like structures of Paleozoic and Mesozoic formations, create favorable conditions for water accumulation. On the other hand, it should be noted that the region is significantly geologically diverse, which does not preclude the use of all Mesozoic complexes, starting with the Triassic and ending with the Cretaceous. When considering heat pump-assisted installations, the temperature of the lower source directly affects the increase in the total power efficiency of the installation [29].

Probably the most thermally favorable area is in the western and northern areas of Kielce District. In these complexes accumulate waters with temperatures reaching up to 60 °C. Such high temperatures can be caused by deep fault zones reaching 3 km below sea level. There is an extensive system of fractures and fracture zones, which allow the mixing of underground thermal waters. However, the presence of waters with such high temperatures requires confirmation by deep drilling [30].

4.2. Evaluation of potential based on calculations of thermal power of intakes

4.2.1 Factors considered in assessing potential

In assessing the thermal potential of groundwater, the key parameters were temperature, intake capacity and water chemistry. An important aspect is the capacity of the supply well. It is estimated that water-to-water heat pumps of small capacity require a minimum supply of 1.5 m^3/h, and for industrial pumps the flow rate needed can reach 15 m^3/h. For example, 1 well with a flow rate of 90 m^3/h is needed to obtain a power of 1 MW [12]. High water capacities are found in all possible wells in the Świętokrzyskie region, that is, the Jurassic, Cretaceous, Quaternary, Tertiary, Permian, Devonian and Triassic. The depth interval of the intakes ranges from 0 to 150 m below sea level, giving great prospects for use as a bottom source of heat in low-temperature systems, provided the water quality is good. Consideration of the county's aquifers focused on 147 drilled wells. The intakes, depending on local needs and location, have different depths. The sites are significantly different in this regard, with the shallowest well being 8 m below ground level and the deepest 160 m.

The composition of water is a key criterion when selecting a lower heat source. The chemical and physical properties of water can corrode the lower heat source system and, if a heat exchanger is not used, also damage the evaporator. High levels of iron and manganese in the water cause clogging of discharge wells [31-32].The risk of water pollution also exists in shallow water [30]. On the area of Kielce District, zones particularly exposed to water pollution (zones of shallow waters with a free groundwater table) include: the area around large excavations of mining plants in which the exploitation of rock resources is carried out below the groundwater table such as "Kowala", "Trzuskawica", "Jaźwica", "Ostrówka" [17, 19] and on the side of high iron and manganese levels include: The landfill for Kielce in Promnik [19] and waters in Quaternary formations near the town of Morawica [17], waters of the Devonian level near Psary - Stara Wieś [30], and waters of the Middle Triassic level in the area of Ruda Strawczyńska [19].

4.2.2. Potential of groundwater intakes for heating purposes

The results of the estimated heat capacities for 147 groundwater intakes in Kielce District are summarized below (Table 2), and the coefficient of efficiency of heat pumps. In the case of exceeded values of Fe and Mn (>1mg/l), a note about the possible risk of corrosion of the installation has been added to the table. The calculations were made using the assumptions discussed in the methodology chapter.

Table 2. Thermal power for wells in Kielce District and heat pump efficiency factor.

No. of hole	**Polish name of the hole**	**A** [1]	**Q [kW]**	**T[°C]** [2]	**COP T** [3]	**Comments**
BH6 7/3	Bodzentyn wodociąg	0.91	549.73	11.82	6.64	
BH6 7/337	Bodzentyn wodociąg komunalny	0.91	25.81	12.92	6.98	
PG Kielce 2666	Bodzentyn wodociąg	0.91	241.05	12.9	6.97	
BH6 7/372	Bodzentyn Z-dy POW	0.91	317.3	11.82	6.64	
BH6 7/6	Bodzentyn Zakład Mleczarski	0.91	72.99	12.84	6.95	
BH6 7/5	Bodzentyn Sp. Rękodz. Ludowego	0.91	14.08	10.76	6.35	
BH6 7/7	Bodzentyn Cegielnia	0.91	7.31	10.23	6.22	
BH6 7/398	Bodzentyn wodociąg wiejski	0.91	367.12	13.37	7.12	
BH6 7/445	Bodzentyn ŚPN	0.91	100.55	10.76	6.35	
BH6 7/397	Bodzentyn wodociąg wiejski	0.91	573.24	12.62	6.88	
BH6 7/590	Brzezinki Szkoła Podstawowa	0.92	5.52	10.27	6.23	
UW Kielce 2378	Brzezinki Leśniczówka	0.92	31.29	10.72	6.34	
BH 5/431	Mąchocice Szkoła Podstawowa	0.92	13.85	11.61	6.58	Fe ↑
BH 5/87	Ciekoty Ośr. Wypoczynkowy	0.91	60.58	10.48	6.28	Fe ↑
BH 5/88	Ciekoty Ośr. Wypoczynkowy	0.91	113.26	10.35	6.25	Fe ↑
BH 5/569	Ciekoty Ośr. Wypoczynkowy cpn	0.91	105.93	10.35	6.25	Fe ↑
BH 5/570	Ciekoty Ośr. Wypoczynkowy cpn	0.91	37.92	10.43	6.27	Fe ↑
BH 5/86	Mąchocice „Ameliówka”	0.91	17.71	10.25	6.22	Fe ↑
BH 5/350	Mąchocice Szkoła Podstawowa	0.91	8.62	11.17	6.46	efficiency↓
BH 5/565	Leszczyny Skała wieś	0.91	29.53	12.05	6.71	
BH 5/251	Bęczków Szkoła Podstawowa	0.91	9.36	10.75	6.35	efficiency↓
BH 5/441	Leszczyny Zlewnia Mleka	0.91	10.46	10.99	6.41	
BH 5/247	Radlin Szkoła Podstawowa	0.92	12.92	10.84	6.37	
BH 5/249	Radlin Szkoła Podstawowa	0.92	26.41	10.82	6.37	
BH 5/465	Górno RSP	0.91	70.72	11.08	6.44	
BH 5/535	Krajno wieś	0.92	904.80	11.64	6.59	
BH 5/536	Krajno wieś	0.92	717.62	11.99	6.69	
BH 5/571	Górno wodociąg grupowy	0.91	59.31	11.37	6.52	
BH 5/503	Górno Ośrodek Zdrowia	0.92	229.95	10.95	6.40	
BH 5/252	Górno Szkoła Podstawowa	0.92	3.47	10.97	6.41	efficiency↓
BH 5/253	Górno Zlewnia Mleka	0.92	63.03	10.95	6.40	
BH 5/254	Górno Kamieniołom”Józefka”	0.93	139.28	12.48	6.84	
PG Kielce 2317	Górno Zakł. Mas Bitumicznych	0.91	54.73	10.73	6.35	
BH 5/61	Bieliny wieś	0.92	414.92	12.60	6.88	
BH 5/344	Bieliny wieś	0.92	434.74	12.96	6.99	
BH 5/62	Bieliny Ośrodek Zdrowia	0.93	24.73	11.64	6.59	

BH 5/527	Podłysica wieś	0.94	42.48	11.19	6.47	
PG	Huta Nowa wieś	0.93	20.04	12.83	6.95	
PI 05 494	Wólka Kłucka Szkoła Podst.	0.9	23.94	11.86	6.65	
UW 2877a	Skoki Rolnicza Sp. Produkcyjna	0.9	37.46	11.31	6.50	
PI 05 493	Piaski Szkoła Podstawowa	0.93	43.49	11.92	6.67	
PI 05 4	Cierchy Szkoła Podstawowa	0.92	191.99	12.17	6.75	
PI 02 522	Wielebnów wodociąg wiejski	0.91	704.9	11.31	6.50	
PI 02 13	Snochowice Nadleśnictwo	0.9	20.14	10.77	6.35	
PI 05 576	Ruda Strawczyńska wodociąg	0.9	264.37	13.74	7.24	
PI 05 573	Ruda Strawczyńska wodociąg	0.9	648.44	13.57	7.19	
PI 05 5	Oblęgorek Leśnictwo	0.93	42.9	11.14	6.46	
PI 05 7	Oblęgorek Szkoła Podstawowa	0.91	16.81	11.02	6.42	
PI 05 8	Oblęgorek Kurnik (prywatny)	0.91	8.78	11.29	6.49	efficiency↓
UW w Kielcach	Ruda Strawczyńska Spółdzielnia	0.9	15.88	10.93	6.40	Fe↑
PI 05 470	Strawczyn POM i wodociąg wiejski	0.9	650.84	11.66	6.60	
PI 05 3	Strawczyn Szkoła Podstawowa	0.9	15.86	11.20	6.47	
PI 05 59	Promnik POM	0.91	54.29	11.06	6.43	
PI 05 589	Micigózd Zakład Energetyczny	0.9	47.99	11.44	6.54	
PI 05 61	Micigózd Szkoła Podstawowa	0.91	21.73	11.02	6.42	Fe ↑
UW w Kielcach	Gnieździska. Zakład "LIPIA"	0.9	364.99	10.73	6.35	
PI 02 478	Gnieździska wodociąg wiejski	0.9	1006.2	11.25	6.48	
PI 02 29	Gnieździska Szkoła Podstawowa	0.9	21.84	10.36	6.25	
PI 02 30	Gnieździska SKR - Tuczarnia	0.89	17.37	11.22	6.48	
PI 02 451	Wierna Rzeka Plebania	0.89	38.71	10.54	6.30	
PI 05 492	Rykoszyn Nastawnia PKP	0.9	30.04	10.49	6.28	Fe ↑
PI 05 98	Piekoszów Dworzec PKP	0.91	1493.4	13.39	7.13	
PI 05 100	Piekoszów Wodociąg wiejski	0.91	551.47	12.28	6.78	
PI 05 102	Piekoszów Gosp. Ogrodnicze	0.91	1019.6	12.06	6.71	SO_4^{2-} ↑
PI 05 477	Piekoszów wodociąg wiejski	0.91	279.01	12.94	6.98	
PI 05 101	Piekoszów Gosp. Ogrodnicze	0.91	205.38	13.28	7.09	
PI 05 91	Miedzianka Zakł. Wapienniczy	0.9	959.43	12.30	6.78	
PI 05 595	Zawada wodociąg wiejski	0.92	34.54	12.24	6.77	
RBDH 6 PI 02/1	Lasocin SKR	0.91	40.62	11.58	6.58	
RBDH 6 PI 02/526	Lasocin Leśniczówka; teraz Wieś	0,9	337.03	11.60	6.58	
RBDH 6 PI 02/528	Piaski Gajówka	0.9	39.70	11.82	6.64	
WOŚ ŚUW 2629	Marianów Cegielnia	0.9	68.84	10.91	6.39	
PI 05 19	Tumlin Szkoła Podstawowa	0.94	36.74	12.34	6.80	
PI 05 426	Tumlin Wykień Zlewnia Mleka	0.92	21.14	11.26	6.49	
PI 05 47	Kajetanów kamieniołom	0.94	629.35	12.84	6.95	
PI 05 13	Ciosowa Garbarnia	0.91	24.36	10.98	6.41	
PI 05 62	Miedziana Góra "Laskowa"	0.91	79.35	12.49	6.84	
PI 05 437	Łazy prywatny	0.91	5.38	10.78	6.36	efficiency↓
PI 05 78	Masłów wodociąg wiejski	0.93	446.4	11.39	6.52	

PI 05 105	Szczukowice Ferma Cieląt	0.9	444.1	14.08	7.36	
PI 05	Szczukowice Urząd Gminy	0.9	336.71	11.89	6.66	
PI 05 243	Cedzyna Ośr. „Przemysłowki”	0.91	102.78	11.01	6.42	
PI 05 244	Leszczyny wodociąg wiejski	0.91	825.29	12.59	6.87	
PI 05 587	Wola Kopcowa wodociąg wiejski	0.91	632.42	11.67	6.60	
PI 05 130	Jaworznia kamieniołom	0.92	66.8	14.57	7.54	
BH 6 05/501	Bolmin Wieś	0.9	391.23	11.99	6.69	
BH 6 05/259	Polichno Osiedle Mieszkaniowe	0.91	1018	12.48	6.84	
BH 6 05/504	Zelejowa Wieś	0.91	24.11	11.68	6.60	SO_4^{2-} ↑
BH 6 05/271	Czerwona Góra Szpital	0.9	348.34	12.48	6.84	
BH 6 05/552	Korzecko Wieś	0.9	150.37	11.63	6.59	
BH 6 05/261	Chęciny Miasto	0.92	374.92	12.26	6.77	
BH 6 05/264	Starochęciny Wieś	0.89	444.73	11.37	6.52	SO_4^{2-} ↑
BH 6 05/272	Bolechowice Kam. „Jaźwica”	0.9	421.85	11.84	6.65	
BH 6 05/263	Tokarnia Wieś	0.9	1646.7	11.92	6.67	
BH 6 05/262	Tokarnia Kamieniołom	0.89	47.43	11.27	6.49	
UWKielce KR 2281	Tokarnia – Wolica Budynek PKP	0.89	90.03	10.9	6.39	
BH 6 05/265	Wolica Szkoła Podstawowa	0.89	33.51	10.64	6.32	
BH 6 05/268	Wolica „Prelbud”	0.89	427.16	12.34	6.80	Fe; SO_4^{2-} ↑
BH 6 01/5	Siedlce Osiedle „Murowaniec”	0.9	19.55	11.46	6.54	
BH 6 05/273	Bolechowice Wieś, Kamieniołom	0.91	308.94	12.81	6.94	
PG Kielce 2491	Nowiny-Sitkówka Za-d „Nowiny”	0.9	1966.4	12.93	6.98	
BH 6 05/274	Nowiny-Sitkówka Za-d „Nowiny”	0.9	2579.3	13.08	7.02	
BH 6 05/289	Sitkówka „Prelbud”	0.9	337.36	10.92	6.39	Fe↑
BH 6 05/290	Sitkówka PKP – Stacja Sitkówka	0.9	670.35	10.67	6.33	
BH 6 05/491	Posłowice Baza Sprzętu Kolejow.	0.9	220.7	12.58	6.87	
BH 6 05/310	Sitkówka -Kowala „Trzuskawica”	0.9	5757.3	13.11	7.03	
BH 6 05/599	Sitkówka – Kowala„Trzuskawica”	0.9	659.37	12.88	6.96	
BH 6 05/456	Dyminy Zakłady Drobiarskie	0.9	2258.2	13.29	7.09	
BH 6 05/519	Mójcza Wieś	0.9	68.13	11.16	6.46	
BH 6 05/383	Suków Stacja IMiGW	0.9	110.47	12.14	6.74	
BH 6 05/385	Sutków – Papiernia	0.9	5403.6	12.42	6.82	
BH 6 05/591	Niestachów Wieś	0.9	290.27	11.74	6.62	
BH 6 05/324	Radkowice Stacja Energetyczna	0.89	41.35	10.38	6.26	Fe↑
BH 6 05/323	Radkowice Kamieniołom	0.89	60.82	11.53	6.56	Fe↑
BH 6 05/368	Dyminy Fabryka Domów, Wieś	0.9	2726.8	12.68	6.90	
BH 6 05/365	Bilcza RSP	0.9	194.1	12.61	6.88	
BH 6 05/366	Bilcza – Podsukowie	0.9	451.46	12.53	6.85	
BH 6 05/395	Kaczyn Ośrodek „Słowa Ludu”	0.9	67.29	10.67	6.33	
BH 6 05/425	Brzeziny RPS – Baza, ferma owiec	0.89	71.16	10.46	6.28	SO_4^{2-} ↑
BH 6 05/328	Brzeziny Zlewnia Mleka	0.89	27.10	10.82	6.37	
BH 6 05/559	Brzeziny Wytwórnia Wód	0.89	2713.9	13.48	7.16	
BH 6 05/361	Łabędziów Kamieniołom	0.89	376.09	11.15	6.46	

BH 6 05/449	Bilcza – Zastawie RSP	0.9	121.18	13.60	7.20	
UW Kielce 3234	Marzysz I Zw.Komun.Wodoc.	0.9	473.56	12.99	7	
BH 6 05/394	Marzysz II Zw.Komun.Wodoc.	0.9	913.78	12.50	6.84	
BH 6 01/268	Łukowa Rolnicza Spółdzielnia	0.9	45.9	11.16	6.46	
BH 6 01/6	Łukowa Szkoła Podstawowa	0.9	78.63	11.76	6.63	
BH 6 01/664	Łukowa Zespół Wsi	0.91	1665.7	12.23	6.76	
BH 6 01/549	Dębska Wola Wieś, RSP	0.9	612.87	11.84	6.65	
PG Kielce 2247	Morawica Szkoła Podstawowa	0.89	10.11	10.79	6.36	
BH 6 01/360	Morawica Szpital Psychiatryczny	0.89	682.45	11.52	6.56	
BH 6 01/681	Radomice Mitpol – Prywatny	0.89	73.52	11.32	6.5	
BH 6 01/599	Brudzów RSP	0.9	75.97	11.53	6.56	
BH 6 01/10	Dębska Wola Posterunek Tele.	0.9	41.05	10.78	6.36	
BH 6 01/11	Dębska Wola Dworzec PKP	0.9	317.11	11.35	6.51	
BH 6 01/437	Chałupki RSP	0.91	34.19	12.17	6.74	
BH 6 01/16	Skrzelczyce Wieś	0.91	127.28	11.08	6.44	
BH 6 01/439	Grabowiec Zespół Wsi	0.9	488.84	11.46	6.54	
BH 6 01/113	Lisów Wieś	0.91	33.57	11.55	6.57	SO_4^{2-} ↑
BH 6 01/424	Piotrkowice Zakł. Wylęgu Drobiu	0.91	45.99	11.59	6.58	
BH 6 01/30	Piotrkowice Wieś	0.9	230.73	11.20	6.47	
BH 6 01/454	Górki -Maleszowa Wieś	0.91	221.27	11.34	6.51	
BH 6 7/1	Wzdół Rządowy Agronomówka	0.93	17.15	10.90	6.43	conductivity↑
UW Kielce 2314	Wzdół Rządowy prywatny	0.93	3.49	10.99	6.45	efficiency↓
BH6 7/383	Wzdół Parcele wieś	0.93	639.54	11.87	6.7	
BH6 7/2	Leśna Szkoła Podstawowa	0.92	32.64	11.68	6.64	
BH6 7/8	Sieradowice Stacja Hod. Roślin	0.96	498.55	11.27	6.54	

[1] constant depending on the height above sea level acc. Table 1
[2] temperature of water at given depth acc. (1) formula
[3] adjusted efficiency ratio acc. (3) formula

The highest estimated temperature is 14.57 °C, and it is also the deepest intake included in the calculations (160 m). The well number is PI 05 130 (a municipal intake supplying the rural water supply in Jaworzno). The largest number of wells, 61, are located, in the temperature range of 11°C to 12 °C which accounts for 42 % of the analyzed intakes. 38 sites, or 26 %, are formations with temperatures of less than 11°C. 36 wells (24 %) have water temperatures in the range of 12 °C to 13 °C. The penultimate temperature range, 13 °C to 14 °C, accounts for 10 sites (7 %). Only two wells have temperatures in the 14 °C to 15 °C range. A directly related data to temperatures is the energy efficiency coefficient. The largest calculated coefficient is 7.54, and the smallest coefficient value is 6.22.

The estimated values of thermal power resources range from 3.47 kW to 5757.34 kW. Such large differences in the possibility of obtaining heat, is due to a few issues. Wells that are used for private use and municipal wells were selected for the calculations. Municipal formations have a higher capacity, so the possibility of development as a heat source also increases. Similarly, private wells usually have lower capacities. The vast terrain and complex geological structure leads to the extraction of water from different aquifers. The last aspect is the different depth of the intakes which has the greatest impact on their temperature and calculated heat capacity [33].

The total heat capacity of the 147 wells included in the calculations is 59186.9 kW. 30 wells failed to meet the minimum requirements as a lower heat source due to low capacity and poor groundwater conditions. The total capacity of the non-compliant wells is 3060.33 kW. Thus, the total possible amount of heat capacity that can be used is 56126.57 kW. The heat demand in the room, depending on the insulation used, can range from 60 W/m^2 to 200 W/m^2 [23]. To estimate the heating capacity of the well, it was assumed that a heating unit of 8 kW is needed for an average single-family home. The total of single-family homes that can be supplied with water-to-water heat pump installations is 7015. A map was drawn up with the locations of all calculated groundwater intakes (Fig. 11).

Analyzing the location of the objects on the map, the area of the city of Bodzentyn, the area around the village of Górno, the village of Piekoszów, the city of Morawica and the village of Wolica can be considered as an area with a favorable location of groundwater intakes with high thermal power.

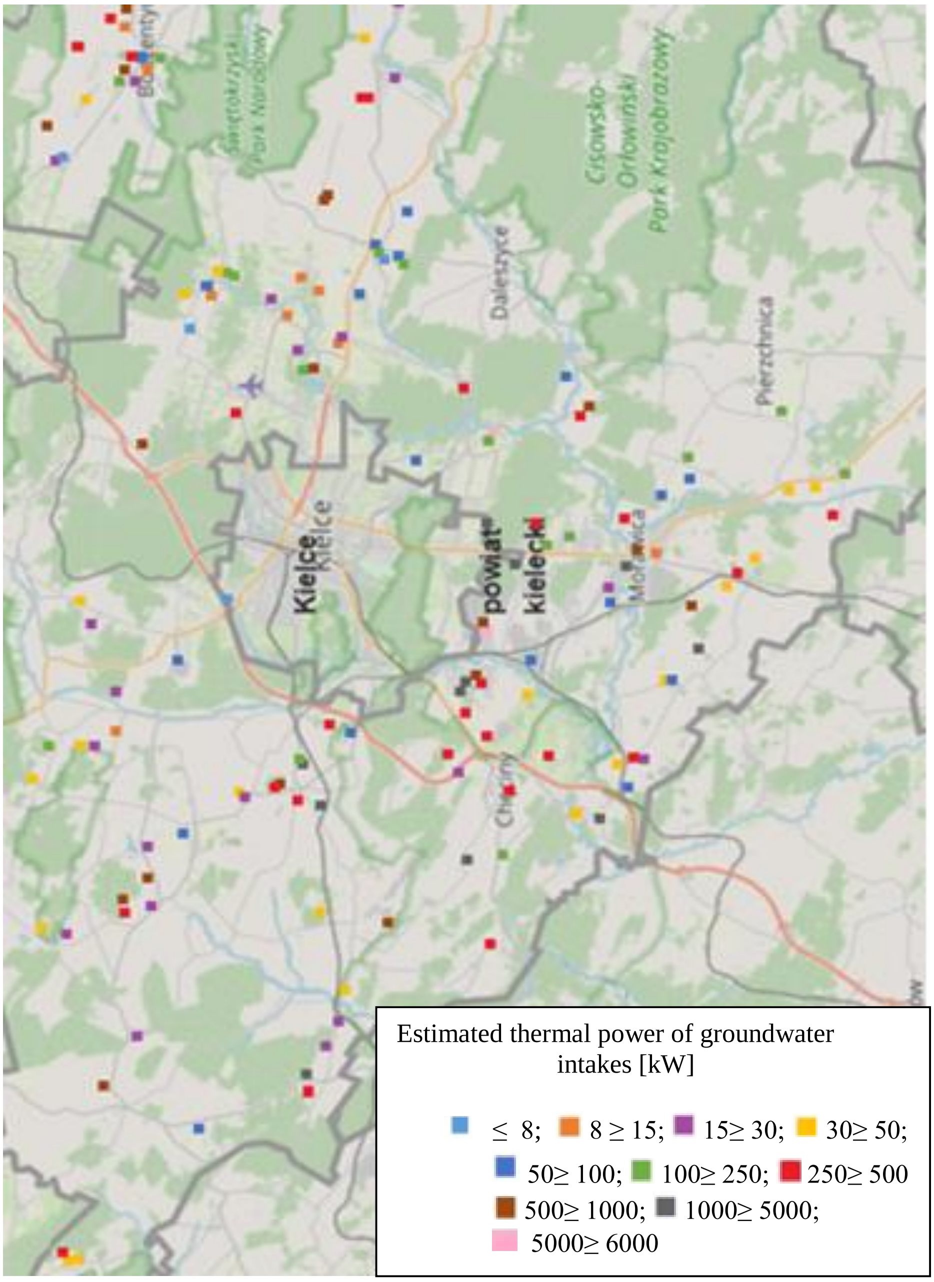


Fig. 11. The map of groundwater intakes with estimated thermal power

5. CONCLUSION

In the present study, the thermal power and energy efficiency index of heat pumps were estimated for 147 groundwater intakes of Kielce District within the hydrogeological map sheets MHP 813–817, MHP 850–851. The possible power to be obtained in the study area is 56126.57 kW, but local variations are evident. In 93 % of the studied intakes, the coefficient of efficiency was set at a level greater than 6.3. Lower source temperatures had a large impact on such a good result, as 74 % of the temperatures are between 11 and 15 °C. In the analyzed area, prospective areas (Bodzentyn, the area around the village of Górno, the village of Piekoszów, the town of Morawica and the village of Wolica) were identified for the development of low-temperature geothermia supported by water-to-water heat pumps. The data obtained can be used as a tool to support the development of RES in the municipalities of Kielce District, reducing low emissions and providing a basis for sustainable development. The study also informs and promotes the use of low-temperature geothermal in Kielce District.

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