INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

No IV/1/2018, POLISH ACADEMY OF SCIENCES, Cracow Branch, pp. 961-972
Commission of Technical Rural Infrastructure

DOI: https://doi.org/10.14597/INFRAECO.2018.4.1.066

VARIABILITY OF BASIC GEOTHERMAL WATER PARAMETERS IN CHOCHOŁÓW PIG-1 BOREHOLE IN THE WESTERN PART OF THE PODHALE BASIN

Agnieszka Operacz
University of Agriculture in Krakow

Abstract

Geothermal waters under national conditions have the status of minerals, which means that their exploitation is carried out in accordance with the provisions of Geological and Mining Law. In the area of the Podhale Basin, one of the boreholes that extracts water of elevated temperature is the Chochołów PIG-1 borehole which constitutes the basis for the functioning of the Chochołowskie Termy recreation complex. The main feature of the waters intake due to the correct functioning of the complex is the stability of temperature and physicochemical parameters. The variability of most important hydrogeological parameters (temperature, SEC, SO42-, Cl-, HCO3-, Ca2+, Mg2+, Na+) with available data base were chosen for the analyzes. These parameters determine economic viability and proper conditions for the technical exploitation of geothermal borehole Chochołów PIG-1. Water chemistry has been studied in the area of ionic index markings determining the type of exploitating geothermal water. This paper presents the results of analyzes of selected parameters in the years 2016-2017 and indicates trends in their contents in the given period. The general conclusion is that under operating conditions in accordance with the approved performance, physicochemical parameters are characterized by relative stability. The appropriate exploitation of water from the Chochołów PIG-1 borehole allows for maintaining the proper temperature, which is the underpinning for the functioning of the recreation and balneology complex of the Chochołowskie Termy.

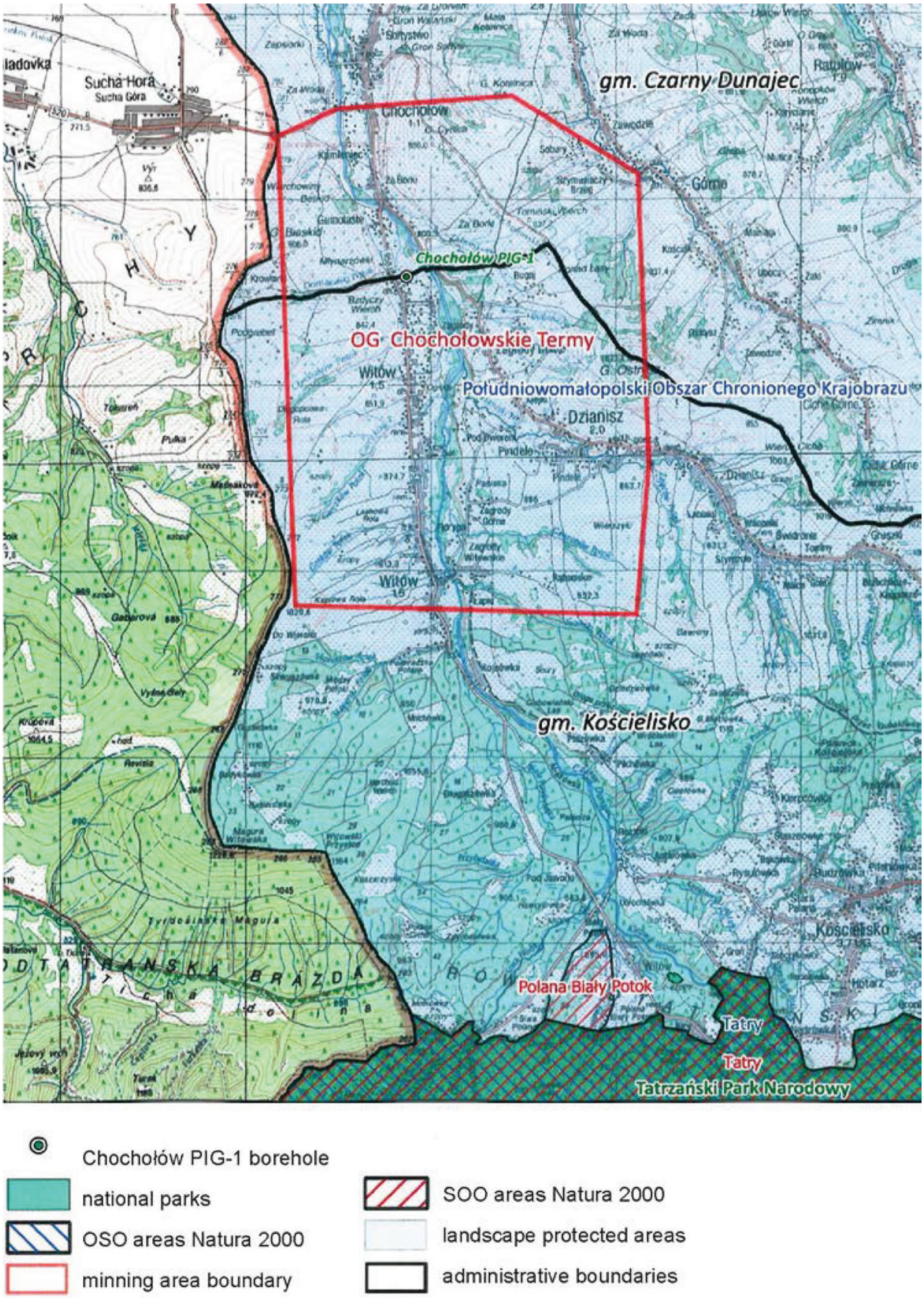
Keywords: geothermal waters, groundwater temperature, common groundwater ions, Podhale Basin

INTRODUCTION

Geothermal waters according to National Geological and Mining Law (Journal of Laws 2011 No. 163, item 981, as amended) are defined as ground waters whose temperature measured at the outflow from natural sources or boreholes reaches at least 20°C. This value is a conventional limit used for many years in balneology and is based on the relationship to the temperature of the human body. In Poland, geothermal waters are considered a mineral and are therefore subject to all the provisions of the Geological and Mining Law. In the Małopolska Province, geothermal waters were regionally detected in the area of the Podhale Basin (the Internal Carpathians). The Podhale Basin is one of the most important prospective areas in Poland in terms of the occurrence of geothermal waters (Kępińska 2015, Bujakowski and Barbacki 2004, Bujakowski *et al.* 2016) which strongly affect the tourism development of the area (Bugajski *et al.* 2017). These waters are characterized by temperatures reaching almost 90ºC and by low mineralization values of up to 3 $g \cdot dm^{-3}$. These parameters determine economic viability and relatively good conditions for the technical exploitation of geothermal waters (Huculak *et al.* 2015, Operacz and Chowaniec 2018). The main feature of the waters intake due to the correct functioning of the complex is the stability of temperature and main physicochemical parameters (SEC, SO_4^{2-}, Cl^-, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+). The scope of the investigation was to find and indicates trends in their contents in the available period 2016-2017. The general conclusion of the analyzes is that under operating conditions in accordance with the approved performance, physicochemical parameters are characterized by relative stability. The achieved results could determine the optimistic scenario for further functioning of the recreation and balneology complex Chochołowskie Termy.

HISTORY OF THE BOREHOLE

The Chochołów PIG-1 borehole was drilled in the years 1989-1990 within the framework of the previous project „Geological research project determining resources and conditions for the exploitation of energy resources in the Podhale Basin" (Sokołowski *et al.* 1987). The project provided for nine deep drillings. Only six of them were completed, including the „Chochołów PIG-1" borehole.



Source: own – modified (Bielec and Operacz 2018)

Figure 1. Location of Chochołów PIG-1 borehole

The „Chochołów PIG-1" borehole was executed in the northern part of Witów, Kościelisko commune, Tatra County in Zakopane (Figure 1).

The results of geological and hydrogeological surveys of the Chochołów PIG-1 borehole were presented in the hydrogeological documentation developed in November 1992 (Chowaniec *et al.* 1992). The inflow of water in the borehole was found below the depth of 3218.0 m from the Middle Triassic dolomites. At the final borehole depth of 3572 m, hydrogeological studies showed that the self-flow rate amounted to 36.0 $m^3 \cdot h^{-1}$. The pressure on the head oscillated around the value of 16 atm. At the outflow, the tested water had a temperature of 70 ^oC and mineralization of 1.65 $g \cdot dm^{-3}$ as well as the prevalence of sulfate-chloride-sodium-calcium ions.

In the years 1996-1997, based on the „Hydrogeological research project of geothermal waters in the Podhale Basin" (Chowaniec *et al.* 1995), hydrogeological investigations were carried out in the Podhale Basin. The results were presented in the „Hydrogeological documentation of the geothermal water resources of the Podhale Basin" (Chowaniec *et al.* 1997). As part of the research, exploitation resources of some boreholes were determined. At that time, the exploitation resources of the Chochołów PIG-1 borehole at the level of 160 $m^3 \cdot h^{-1}$ were estimated. The resources were approved by the Minister of Environmental Protection, Natural Resources and Forestry. The decision was issued for a period of 10 years i.e. until the end of 2007.

In 2009, a hydrogeological documentation was prepared (Józefko and Bielec 2009), in which the exploitation resources of the Chochołów PIG-1 geothermal water extraction were verified. The analysis of static head pressure, recorded from 2006 until May 2009, consisted in the basis for the verification of resources. The exploitation resources were set at 120 $m^3 \cdot h^{-1}$ at a low-pressure area of 95 m. At this level of resources, the outflow water temperature amounted to 82ºC. In 2018, an addition to the hydrogeological documentation was prepared (Bielec and Operacz 2018). In the addition, new exploitation resources were established for the extraction of geothermal water of the Chochołów PIG-1. Currently, they amount to 160 $m^3 \cdot h^{-1}$ at a low-pressure area of 145.5 m. Water type: SO_4-Ca-Mg-Na. Water mineralization: 1050-1300 $mg \cdot dm^{-3}$. The outflow water temperature is 89.8ºC.

GEOLOGICAL AND HYDROGEOLOGICAL CONDITIONS

There are two main geological units in the studied area: the Paleogene Podhale Basin and the Tatra massif located in the south of it.The Tatra Massif consists of crystalline metamorphic series as older formations and the Pre-Permian granitoid intrusions younger than them as well as Mesozoic sedimentary series, among which, in addition to dolomites, limestones and marls, there are also sandstones, shales and siltstones. The massif is divided into two faction tectonic zones: the southern one, called the peak (wierchy), which has a large spread and the northern one, called the regle, stretching as a narrow strip along the northern edge of the Tatra Mountains. The formations of the Tatra Massif are submerged towards the north under the Paleogene formations, i.e. the formations of the Podhale Basin. The Podhale Basin is built of sandstone-slate formations lying on the Mesozoic Tatra units (Górecki *et al.* 2015). The formations that fill the Podhale Basin consist of two different sedimentary cells. The bottom cell – carbonate, called the Tatra or Numulite eocene, is represented by organodetrital limestones, conglomerates containing crumbs of carbonate rocks and dolomites. The upper cell – flysch, called the Podhale flysch, is represented byshale-mud-and-sandstone formations.

The supply area of sub-flysch aquifers with rainwater is located in the Tatra Mountains. Rainwater infiltrating this area moves through a system of karstic slots and cavities towards the north, in accordance with the direction of collapse of the Tatra series. Part of the waters has a fairly short circulation because it appears on the surface in the form of springs or is drained in the valleys. The remaining part of the waters penetrates into the depths, heats up and is extracted as the thermal waters. These waters migrate towards the north in accordance with the direction of collapse of water-bearing series, and then as a result of the tight barrier of the Pieniny rock belt, they flow out in a fan-shaped way towards the east and west beyond the state borders.

In the Chochołów PIG-1 borehole, geothermal water is found within dolomites and highly dolomitic limestone (Middle Triassic), and is extracted in the depth zone from 3191 – 3547 m below the surface area. The borehole extracts the perched aquifer under artesian pressure. Due to favorable hydrodynamic conditions, the exploitation of the Chochołów PIG-1 borehole is carried out in the conditions of self-flow without the use of any mechanical devices.

FINDINGS

The Chochołowskie Termy is one of the largest geothermal complexes in Podhale. The pools are filled with geothermal water extracted from the Chochołów PIG-1 borehole. The complex was opened in June 2016. Permanent supervision over the exploitation of the borehole is exercised by employees of the Thermal Mining Plant „Chochołowskie Termy". Since the moment of commencement of the continuous exploitation of the borehole, monthly analyses of the chemical composition of water have been performed. Water chemistry has been studied in the area of ionic index markings determining the type of geothermal water. Observations of other hydrodynamic parameters have continuously been carried out.

Temperature of extracted waters

The diagrams show graphically recorded temperature variability of extracted water (Fig. 2) in the period January 2016 – December 2017. The Chochołów PIG-1 borehole was exploited in this period with a capacity not exceeding the accepted exploitation resources, amounting to 120 $m^3 \cdot h^{-1}$ in this period.

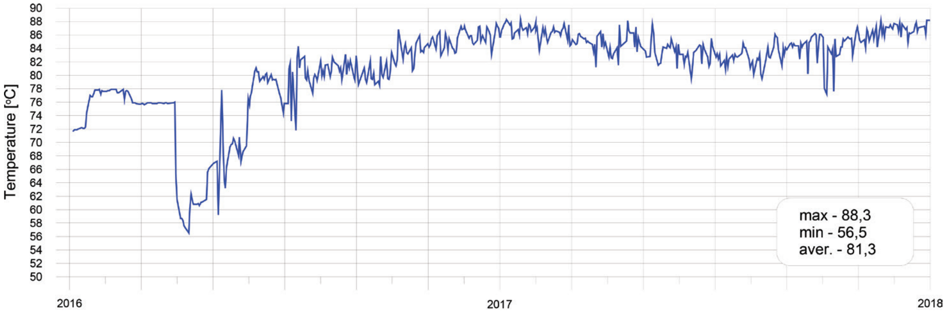


Figure 2. The graph of temperature variability of water from the Chochołów PIG-1 borehole in the period 2016-2017 (Source: own – based on data from Chochołowskie Termy)

During the operation of the borehole, a slight increase in temperature is observed. Bearing in mind the relatively short period of observations, it cannot be unequivocally stated that such an upward trend is permanent. Temperature changes depend on the consumption volume. In periods of less intensive use, a drop in water temperature is observed. Similarly, the increase in extraction results in a rise in temperature. The known dependence of the water temperature on the amount of water collected was confirmed (the smaller the amount of water flowing out, the lower its temperature).

Chemism of extracted waters

On the basis of a physical and chemical examination of water (large analysis) carried out on November 28, 2017, it was found that the thermal water extracted from the Chochołów PIG-1 borehole had a mineralization of 1078,1 $mg \cdot dm^{-3}$ and outflow temperature of 89.7 °C. It was weakly alkaline water of pH = 7.33. Sulphate ion dominated (78.7% mval) among the anions. The content of bicarbonates did not exceed 17.9% mval, and chlorides 3.5% mval. Calcium ions (56.3% mval), magnesium ions (20.2% mval) and sodium ions (20.1% mval) were predominant among the cations. According to the Altowski-Szwiec record, it was thermal water of the SO_4-Ca-Mg-Na type. In the tested water, there was neither H_2S nor other components which would have qualified the water as the specific water. The characteristic of the extracted water according to the Kurłow formula employs the formula:

$$M^{1,08}\frac{SO_4^{\;78}HCO_3^{\;18}Cl^3}{Ca^{56}Mg^{20}Na^{20}K^2}T^{90} \quad \textit{(28 November 2017)} \tag{1}$$

Physicochemical analyses of water samples collected in 2016-2018 showed that the content of main components showed little variability and varied within the limits of:

SO_4^{2-}	71.5 – 79.3 % mval
HCO_3^-	17.5 – 25.3 % mval
Cl^-	3.20 – 4.35 % mval
Ca^{2+}	53.9 – 57.2 % mval
Mg^{2+}	19.4 – 27.5 % mval
Na^+	16.6 – 21.0 % mval

The above shows that mutual relations between individual components (% mval) fluctuated slightly. The chemical type of water determined according to the classification of Szczukariew-Prikłoński, where the type of water includes ions, the content of which exceeds 20% mval is primarily sulphate-calcium water. The SO_4^{2-} anion and Ca^{2+} cation play a dominant role in the chemical composition of water from the Chochołów PIG-1 borehole. The contents of the remaining main ions: HCO3-, Na+ and Mg2+ are similar in all tests and oscillate around the value of ± 20% mval, which leads to a frequent change in the chemical type of water.

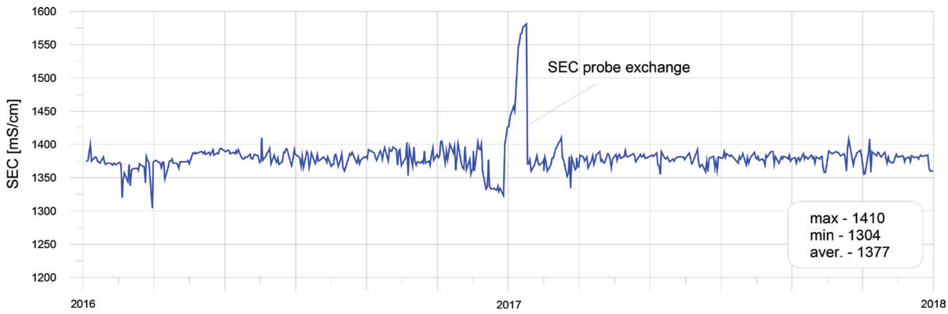


Figure 3. The graph of the variability of SEC from the Chochołów PIG-1 borehole in period 2016-2017 (Source: own – based on data from Chochołowskie Termy)

The specific electrolytic conductivity of water (SEC) provides indicative information on fluctuations and changes in water mineralization. The SEC tests were conducted directly at the borehole on the days of performing other measurements with an accuracy of 1 μS·cm^{-1}. The SEC of water in the period 2016-2017 reached the minimum value of 1304 μS·cm^{-1}, and the maximum value of 1410 μS·cm^{-1}. The amplitude of fluctuations was small and amounted to 106 μS·cm^{-1}. The annual variability is shown in Figure 3.

The content of sulphate ion in the period 2016 – 2017 according to stationary tests, varied from 477.1 mg·dm^{-3} to 647.4 mg·dm^{-3}. The mean of the observation period amounted to 549.26 mg·dm^{-3}. The range of fluctuations in the sulphate ion content did not show an upward or downward tendency (Figure 4).

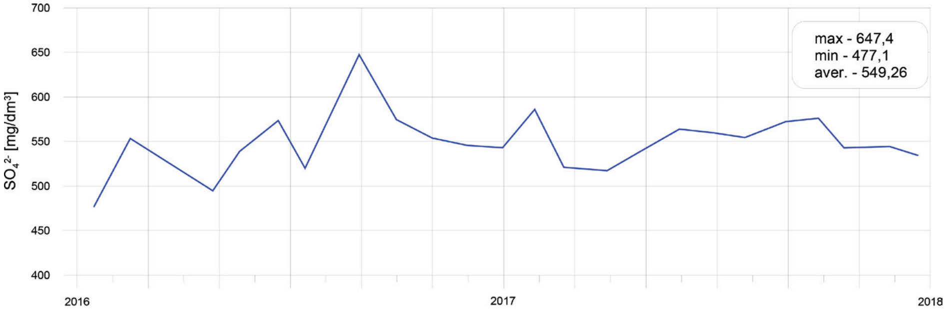


Figure 4. The graph of the variability of SO_4^{2-} content in water from the Chochołów PIG-1 borehole in period 2016-2017 (Source: own – based on data from Chochołowskie Termy)

The content of chloride ion in the analyzed period varied from 12.2 mg·dm^{-3} to 43.5 mg·dm^{-3}. The mean amounted to 21.4 mg·dm^{-3}. The analysis of the chloride ion content during the observation period showed a slight downward trend (Figure 5).

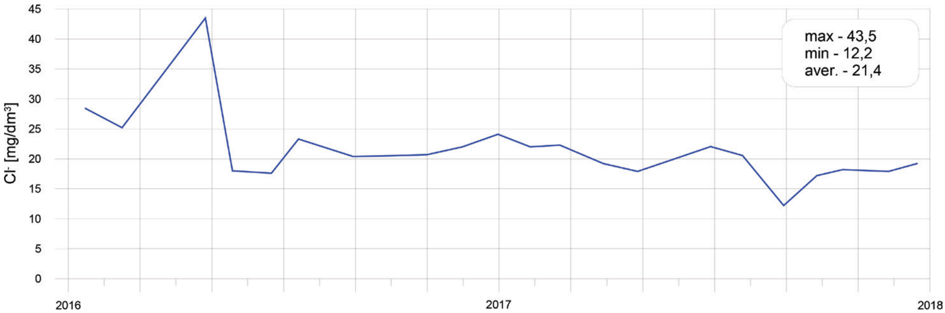


Figure 5. The graph of the variability of Cl^- content in water from the Chochołów PIG-1 borehole in period 2016-2017 (Source: own – based on data from Chochołowskie Termy)

The content of bicarbonate ions in the period 2016-2017 varied from 156.8 mg·dm^{-3} to 244.4 mg·dm^{-3}. The mean of the observation period amounted to 184.9 mg·dm^{-3}. A slight downward tendency can be seen during the observation period in the bicarbonate ion content (Figure 6).

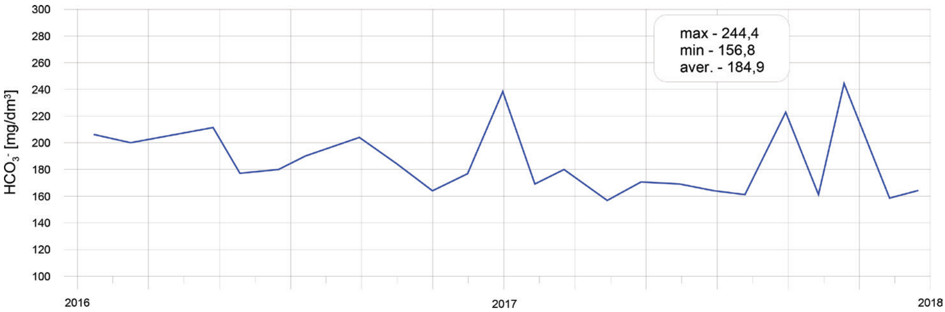


Figure 6. The graph of the variability of HCO_3^- content in water from the Chochołów PIG-1 borehole in period 2016-2017 (Source: own – based on data from Chochołowskie Termy)

The content of calcium ion in the period 2016 – 2017 varied from 160.0 mg·dm^{-3} to 194.4 mg·dm^{-3}. The mean of the observation period amounted to 174.6 mg·dm^{-3}. The range of fluctuations in the bicarbonate ion content showed no clear upward or downward tendency (Figure 7).

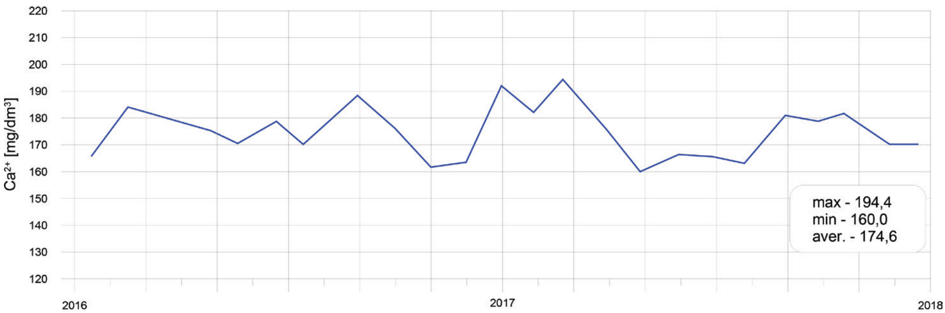


Figure 7. The graph of the variability of Ca^{2+} content in water from the Chochołów PIG-1 borehole in period 2016-2017 (Source: own – based on data from Chochołowskie Termy)

The content of sodium ion in the analyzed period varied from 64.22 mg·dm^{-3} to 82.7 mg·dm^{-3} with no downward trend. The mean of the observation period amounted to 72.37 mg·dm^{-3}. The range of fluctuations in the sodium ion content was small with a slight downward trend (Figure 8).

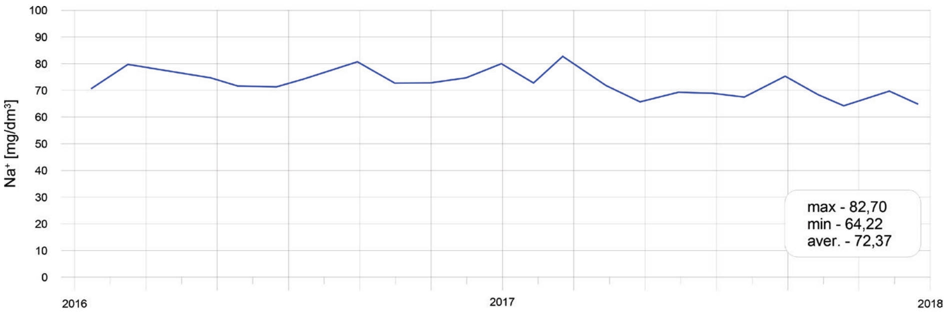


Figure 8. The graph of the variability of Na^+ content in water from the Chochołów PIG-1 borehole in period 2016-2017 (Source: own – based on data from Chochołowskie Termy)

The content of magnesium ion in the period 2016-2017 varied from 33.47 mg·dm^{-3} to 56.18 mg·dm^{-3}. The mean of the observation period amounted to 39.28 mg·dm^{-3}. The range of fluctuations in the content of bicarbonate ion showed no clear upward or downward tendency (Figure 9).

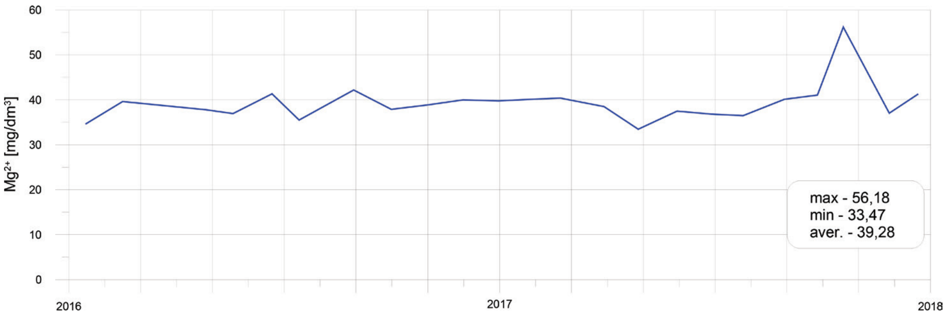


Figure 9. The graph of the variability of Mg^{2+} content in water from the Chochołów PIG-1 borehole in period 2016-2017 (Source: own – based on data from Chochołowskie Termy)

SUMMARY AND CONCLUSIONS

For the proper functioning of the complex, the stability of the chemical composition of geothermal water is crucial. Under operating conditions in accordance with the approved performance, physicochemical parameters are characterized by relative stability. The observed slight downward trend of some ions was not confirmed by a possible decrease in the value of the electrolytic conductivity. Analyzing the results of the performed water tests, as well as land development and the state of the environment in the area of the Chochołów PIG-1 borehole, it should be stated that the extracted water is expected to be characterized by constancy of chemical composition and good bacteriological status. The appropriate exploitation of water from the Chochołów PIG-1 borehole allows for maintaining the proper temperature, which is the underpinning for the functioning of the recreation and balneology complex of the Chochołowskie Termy.

ACKNOWLEDGMENT

The author wishes to thank the Chochołowskie Termy Sp. z o.o. for sharing materials for this article.

REFERENCES

Bielec, B., Operacz, A. (2018). *Dodatek do dokumentacji hydrogeologicznej ustalającej zasoby eksploatacyjne ujęcia wód termalnych „Chochołów PIG-1"*. VENA Sp. z o.o.

Bugajski,, P., Nowobilska–Majewska, E., Nowobilska–Luberda, A., Bergel, T. (2017) *The use of geothermal waters in Podhale in terms of tourism and industrial applications.* Journal of Ecological Engineering 18(6): 185–191. DOI: https://doi.org/10.12911/22998993/75692.

Bujakowski, W., Barbacki, A. (2004) *Potential for geothermal development in Southern Poland*. Geothermics 33(3):383–395. http://dx.doi.org/10.1016/j.geothermics.2003.04.001.

Bujakowski, W., Tomaszewska, B., Miecznik, M. (2016) *The Podhale geothermal reservoir simulation for long-term sustainable production.* Renewable Energy 99: 420-430. DOI: https://doi.org/10.1016/j.renene.2016.07.028.

Chowaniec, J., Olszewska, B., Poprawa, D., Skulich, J., Smagowicz, M. (1992) *Dokumentacja hydrogeologiczna zasobów wód podziemnych – wody termalne. Otwór Chochołów PIG-1.* Arch. NAG, Warszawa.

Chowaniec, J., Długosz, P., Nagy, S., Poprawa, D., Witczak, S., Witek, K., Włodarczyk, J. (1995) – *Projekt badań hydrogeologicznych wód geotermalnych w niecce podhalańskiej*. Arch. NAG, Warszawa.

Chowaniec, J., Długosz, P., Drozdowski, B., Nagy, S., Poprawa, D., Witczak, S., Witek, K. (1997) *Dokumentacja hydrogeologiczna zasobów wód termalnych niecki podhalańskiej*. Arch. NAG, Warszawa.

Górecki, W. Sowiżdżał, A., Hajto, M., Wachowicz-Pyzik, A. (2015) *Atlases of geothermal waters and energy resources in Poland* Environmental Earth Sciences 74: 7487-7495. DOI https://doi.org/10.1007/s12665-014-3832-2.

Huculak, M., Jarczewski, W., Dej, M. (2015) *Economic aspects of the use of deep geothermal heat in district heating in Poland*, Renewable and Sustainable Energy Reviews 49: 29–40, http://dx.doi.org/10.1016/j.rser.2015.04.057.

Józefko, I., Bielec, B. (2009) *Dokumentacja hydrogeologiczna ustalająca zasoby eksploatacyjne ujęcia wód termalnych „Chochołów PIG-1"*. PBG „Geoprofil" Sp. z o.o.

Kępińska, B. (2015) *Geothermal energy country update report from Poland*, 2010–2014. Proceedings World Geothermal Congress 2015, Melbourne, Australia, April 19–24, DOI: https://doi.org/10.1016/j.geothermics.2015.11.003.

Materiały archiwalne Zakładu Górniczego Wód Termalnych „Chochołowskie Termy".

Operacz, A., Chowaniec, J. (2018) *Perspectives of geothermal water use in Podhale basin according to geothermal step distribution.* Geology, Geophysics and Environment vol. 44 (4): 379–389. DOI: http://dx.doi.org/10.7494/geol.2018.44.4.379.

The Geologic and Mining Law – Ustawa Prawo Geologiczne i Górnicze (Journal of Laws of 2016 item 1131) (in Polish).

Sokołowski, J., Doktor, S., Górecki, W., Graniczny, M., Myśko, A., Jawor, E., Karnkowski, P., Ney, R., Nowotarski, Cz., Poprawa, D., Słuszkiewicz, T.. Wysopal, Z. (1987). *Projekt badań geologicznych określających zasoby i warunki eksploatacji surowców energetycznych w niecce podhalańskiej*. Arch. IGSMiE PAN, Kraków (nie publik.).

Sowiżdżał, A. (2018) *Geothermal energy resources in Poland – overview of the current state of knowledge.* Renewable and Sustainable Energy Reviews 82: 4020-4027. DOI: https://doi.org/10.1016/j.rser.2017.10.070.

Eng. Agnieszka Operacz, PhD
University of Agriculture in Krakow
Faculty of Environmental Engineering and Land Surveying
Department of Sanitary Engineering and Water Management
Al. Mickiewicza 21, 31-120 Kraków, Poland
e-mail: a.operacz@ur.krakow.pl
Phone: +48 12 662 40 45
ORCID: 0000-0002-1717-1661

Received: 31.10.2018
Accepted: 07.12.2018