THE QUALITY OF THE ZYGMUNT SPRING WATER (SOUTHERN POLAND) – PRELIMINARY RESULTS

Dominika Dąbrowska, Marek Ruman, Jacek Wróbel

University of Silesia, Faculty of Natural Sciences, Institute of Earth Sciences, Będzińska 60, 41-200 Sosnowiec, Poland

Manuscript received: May 14, 2024
Revised version: August 13, 2024

Dąbrowska D., Ruman M., Wróbel J., 2024. The quality of the Zygmunt Spring water (southern Poland) – preliminary results. *Quaestiones Geographicae* 43(3), Bogucki Wydawnictwo Naukowe, Poznań, pp. 125–133. 1 fig, 1 table.

Abstract: Natural springs are one of the potential sources of water supply, but due to negative anthropogenic impacts, the water quality can deteriorate. The Zygmunt Spring in Złoty Potok does not form the basis of the population's water supply, but it is constantly being exploited by residents and tourists. This study was carried out at Zygmunt Spring in two measurement series for 34 physicochemical and bacteriological parameters. The average electrolytic conductivity (EC) of the water in this spring is about 0.039 $S \cdot m^{-1}$, the pH is about 7.04 and the discharge is equal to 15 $dm^3 \cdot s^{-1}$. The test results were compared with the permissible limits for national drinking water, groundwater quality and WHO standards. The value of the Backman pollution index was calculated for these parameters. This index takes into account parameters that exceed the upper permissible concentrations of contaminants. The Backman Contamination Index value was about −13, but the results of bacteriological analyses indicate a very high number of microorganisms in the water (>300 $cfu \cdot mL^{-1}$), indicating a high health risk.

Keywords: spring, karst, water quality, microbiology, the Backman Contamination Index, risk, Złoty Potok

Corresponding author: Dominika Dąbrowska; dominika.dabrowska@us.edu.pl

Introduction

Society's demand for water of an appropriate quality suitable for drinking is constantly growing. Due to the increase in pollution, providing such resources has become extremely difficult (Stevanović 2010). This phenomenon affects not only developing countries but is a global problem. Globally, approximately 30% of freshwater is groundwater, which is at risk due to climate change and human activities such as industry, urbanisation, mining, and agriculture. Examples of drinking water sources include springs, streams, and dug and drilled wells (Owamah et al. 2013). It is important to remember that on a global scale, karst aquifers are one of the main sources of freshwater (Hamed et al. 2023). In Europe, approximately 5.1% of the surface area contains continuous exposures of carbonate rocks, which are particularly endangered due to the hydrogeological properties of these rocks. This applies not only to the physicochemical parameters but also to bacteriological threats. Springs connect surface and groundwater ecosystems and are therefore often vulnerable to pollution (Todd 2009, Pokładek et al. 2011, Sari et al. 2022) depending on geological, climatic conditions and land use (Ansari et al. 2015, Kayastha 2015, Meng et al. 2016, Kumar et al. 2017, Pinter et al. 2018). The same factors will influence the amount and type of contaminants

https://doi.org/10.14746/quageo-2024-0032
ISSN 2082-2103, eISSN 2081-6383

that will be present in spring water. Moreover, the topography and development of the surrounding area may result in faster migration of contaminants (Gothwal, Shashidhar 2014).

Contaminated water may pose direct or indirect risks to human health (Guo et al. 2022). Typical water contaminants include compounds of organic and inorganic origin, including heavy metals, detergents, fertilisers, pesticides, pharmaceuticals, and biomaterials (Benson et al. 2010). Heavy metals occur naturally in water in trace amounts and are essential for human metabolism, but increased concentrations lead to the development of diseases of the skeletal, nervous and digestive systems (Muhammad et al. 2011). Faecal bacteria from domestic sewage, septic tanks and sewage treatment plants constitute the majority of threats to karst groundwater (Humphrey et al. 2018, Iverson et al. 2020). Springs can be subjected to various tests that help in assessing the quality and quantity of resources. These include primarily hydrological, hydrogeological and bacteriological research. The results of such studies can be interpreted using various methods, including indicator methods (Backman et al. 1998, Gogu, Dassargues 2000, Tałałaj 2014, Zhang et al. 2018).

The aim of this article is to present the current state of knowledge on the water quality of Zygmunt's Spring and to evaluate the hypothesis that water from a spring located in an area under anthropogenic pressure is characterised by an altered chemical composition, based on the examination of the water quality of a karst spring in two series of measurements. The choice of Zygmunt Spring as the subject of research is dictated by the fact that it is a very popular place among tourists in the Kraków-Częstochowa Upland, from which water is often drawn for drinking purposes. The research took into account the physicochemical parameters and selected bacteriological indicators. The Backman Pollution Index was used as an auxiliary method in water risk assessment.

Study area

The research covered the main outflow in the discharge system of the Zygmunt Spring, which is located in the Janów commune (the Silesian Voivodeship), at a distance of 30 km from Częstochowa (southern Poland) with an altitude of 296 m above sea level (Fig. 1). In terms of physical and geographical regionalisation, according to Kondracki (2000), it is located in the Kraków-Częstochowa Upland macroregion and in the Częstochowa Upland mesoregion. The spring is located in the Jurassic plateau and gives rise to the Wiercica catchment. It is a perennial spring. A niche has developed on the slope, from which several springs flow. The spring is located within the Natura 2000 area Ostoja Złotopotocka PLH240020 (Wojtal et al. 2017). Moreover, the spring in Złoty Potok is located within the boundaries of the 'Parkowe' nature reserve, which was established in 1926. It should be noted that this is an area very poor in surface water – typical of karst areas, and has one of the rarest river networks in Poland. Water from the spring creates the Zygmunt Stream, which is 500 m long. Despite the fact that the main source of water supply for the population is groundwater, water from the spring in Złoty Potok is taken all the time by nearby residents and tourists. The close proximity of the road (about 150 m) makes the intake site easily accessible.

The Zygmunt Spring is located in a region with a distinct continental climate. Taking into account the available hourly archival meteorological data from the Institute of Meteorology and Water Management from the nearest observation station (Częstochowa) for the years 1971–1991, the average annual air temperature is 8.18°C, the maximum 31.4°C and the minimum −16.3°C (MIiR 2019). The annual rainfall is approximately 800 mm. The greatest amount of rainfall falls in April. The highest average monthly humidity occurs in January, whereas the lowest is observed in July.

The study site is located in a forested area, but at a distance of about 1 km to the northwest and 2 km to the southeast are agricultural fields, which may be a source of pollution. Hence, according to the hydrogeological map of Poland in scale 1:50,000 (Zembal et al. 2013), the first aquifer has a very high level of vulnerability to pollution in the area.

The Zygmunt Spring is geologically located in the northern part of the Silesian-Kraków Monocline. This area is composed of Jurassic, Cretaceous, Tertiary and Quaternary deposits (Heliasz et al. 1987). The Jurassic formations are represented by plate limestones, marly limestones,

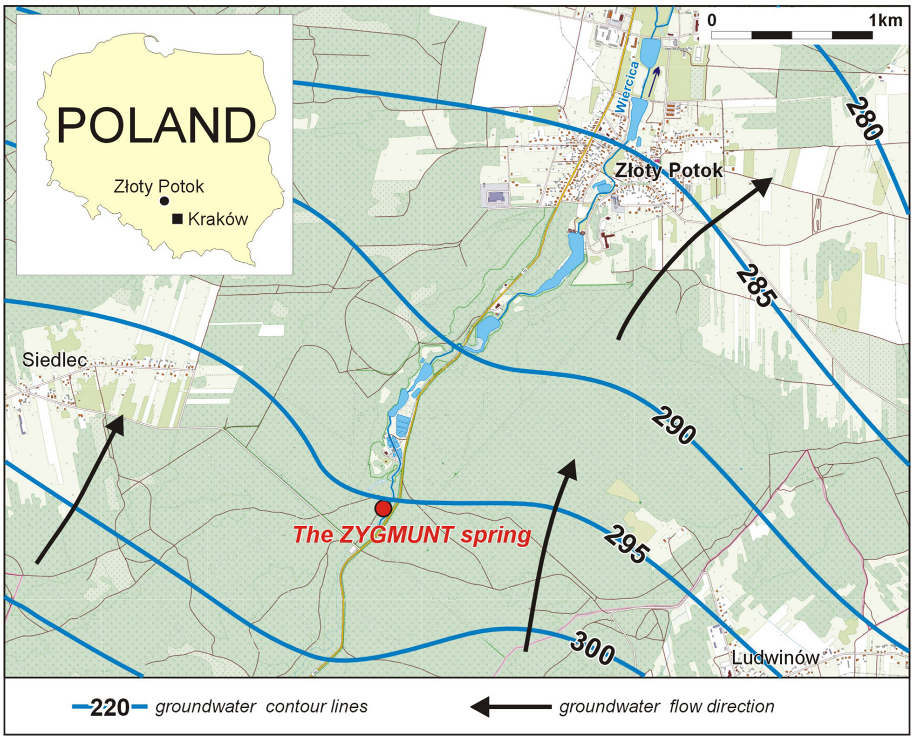

Fig. 1. Map of study area location (based on Pacholewski, Guzik 1997b).

marls, and rocky and fissured, plate limestones of a cream–beige colour, often with flints. The inselberg forms are made of rocky limestone, which is the most resistant to weathering processes. Tertiary formations are mainly represented by various-grained sands and weathered clays with clasts and fine- and medium-grained sands with an admixture of clay minerals. The thickness of the Jurassic formations in the area of the spring is approximately 120 m. The Quaternary formations are represented by sediments and marginal forms of the Central Polish glaciation (boulder clays, sands, end moraine gravels and gravels, sandy eluvia of boulder clays), loess covers, aeolian sands in dunes and boulder clays, river sediments, that is, bottom silts, sands and gravels of floodplain terraces. In the area of the described spring, these deposits are not >1 m thick.

From a hydrogeological point of view, usable groundwater in the commune area occurs in the Upper Jurassic level, including a series of Kelovian, Oxfordian and Kimmeridgian carbonate deposits. This is a fracture-karst level with a water table on the outcrops and a confined groundwater surface under the Quaternary formations. The thickness of this level is up to 350 m, its transmissivity is about 110 $m^2 \cdot 24\ h^{-1}$ and hydraulic conductivity ranges from $6.0 \times 10^{-7}\ m \cdot s^{-1}$ to $9.7 \times 10^{-4}\ m \cdot s^{-1}$ (Pacholewski, Guzik 1997a). Well discharges are also varied, ranging from a few to over 250 $m^3 \cdot h^{-1}$. Discharge of springs in this area ranges from 6 $dm^3 \cdot s^{-1}$ to >1400 $dm^3 \cdot s^{-1}$ (Pacholewski, Guzik 1997a). The flow of groundwater in the main aquifer is in a north-eastern direction. Groundwater quality is good but may be unstable due to lack of isolation from the surface. This causes the waters to be exposed to pollution -high risk (Pacholewski, Guzik 1997b).

Methodology

The spring research included two series of measurements on 25 November 2023 and 18 February 2024. These two measurement series are the beginning of research on the water quality in this spring and will be continued. The average air temperature in October was 10.1°C and rainfall was 90 mm, while in January the average temperature was 4.8°C and rainfall was 73 mm. These are the monthly data before the spring water measurements. It should be noted that from October to February there was no snow cover in the analysed area, so a factor such as snow melt is not considered for the analysis of the measurements.

Field tests included measurements of temperature, electrolytic conductivity (EC), pH, dissolved oxygen and spring discharge using a CC-401 conductivity meter, pH using a CP-411 pH meter, and dissolved oxygen using a CO-401 oxygen meter, produced by Elmetron (accuracy 0.01). Water samples were collected for physicochemical and bacteriological analyses performed in GBA Polska accredited laboratory (laboratory accreditation number: AB 1095). The values of EC, pH, Ca^{2+}, Na^+, K^+, Mg^{2+}, Fe^{2+}, Al^{3+}, Mn^{2+}, Ni^{2+}, Cu^{2+}, $Sr^{2+,}$ S^{2-}, Cl^-, $SO_4^{\ 2-}$, $HCO_3^{\ 2-}$, $NO_3^{\ -}$, $NO_2^{\ -}$, $NH_4^{\ +}$, $PO_4^{\ 3-}$, Kjeldahl nitrogen, TOC, Pb^{2+}, Cd^{2+}, Cr^{6+}, Hg^{2+}, Zn^{2+}, acidity and alkalinity were tested. In the bacteriological scope, coliforms *Escherichia coli*, *Enterococci*, *Clostridium perfringens*, microorganisms at 22 ± 2°C, *Pseudomonas aeruginosa* and microorganisms at 36 ± 2°C were examined. The following PN-EN ISO standards were taken into account in the laboratory tests: 11885:2009 (metals except mercury), 9297:1994 (chlorides), 9280:2002 (sulphates), 9963-1:2001 (bicarbonates), 13395:2001 (nitrogen compounds), 6878:2006 point 4 (phosphates), 1484:1999 (total organic carbon), 12846:2012 point 7 (mercury), 27888:1999 (EC), 9308-1:2014-12, 9308-1:2014-12/A1:2017-04 (coli bacteria), 7899-2:2004 (number of *Enterococci*), 14189:2016-10 (Number of *C. perfringens*), 16266:2009 (Number of *P. aeruginosa*), 6222:2004 (total number of microorganisms at 22 ± 2°C and total number of microorganisms at 36 ± 2°C).

The discharge was obtained by dividing the container volume by the filling time. Three different measurements were made and the average value was used. To improve the reliability of the measurement, the bucket method was used to measure discharge.

The concentration of chemical components in groundwater depends on many processes and conditions, including mineral availability and solubility (Gascoyne 2004), the geochemical environment and exchange processes. Several hydrochemical indicators were used to assess vertical hydrochemical zonation. In order to check whether groundwater is in contact with atmospheric water, the following indicators were used:

$$r\frac{Na^+ + K^+}{Cl^-} \text{ and } r\frac{Na^+ + K^+ + Mg^{2+}}{Cl^-}.$$

If these values are >1, this condition is confirmed. In the case of dynamic stagnation, these values decrease. The origin of spring waters was also determined based on the index $\frac{Ca^{2+}}{Sr^{2+}}$ which >200 for waters enriched by leaching of carbonate rocks (Macioszczyk 1987).

The analytical results from the laboratory were compared with the permissible values contained in the following regulations:

- Regulation of the Minister of Health of 07 December 2017 on the quality of water intended for human consumption (Journal of Laws of 2017, item 2294);
- Regulation of the Minister of Maritime Economy and Inland Navigation of 11 October 2019 on the criteria and method of assessing the status of groundwater bodies (Journal of Laws of 2019, item 2148);
- WHO standards in terms of exceedances of the established limits.

The Backman Contamination Index was used to assess the risk for water in the spring for all parameters mentioned in the regulation (EC, Na^+, Mg^{2+}, Fe^{2+}, Al^{3+}, Mn^{2+}, Ni^{2+}, chlorides, sulphates, nitrogen compounds, Pb^{2+}, Cd^{2+}, Cr^{6+} and Hg^{2+}). This index has been calculated using the following formula (Backman et al.1998):

$$C_d = \sum_{i=1}^{n} C_{fi}$$

where:

$$C_{fi} = \frac{C_{Ai}}{C_{Ni}} - 1$$

- C_{fi} is the contamination factor for the *i*-th component,
- C_{Ai} is the analytical value of the *i*-th component,
- C_{Ni} is the upper range of natural hydrogeochemical background.

The total value of the index is reduced by 1. With an increase in the concentration of a given component in relation to the drinking water limit, the value of the contamination index grows. This index classifies water based on three classes: the threat to groundwater is high in an area wherein the index value is >3, moderate pollution with a value in the range of 1–3 and the low threat when the index value is <1 (Knopek, Dąbrowska 2021).

Results and discussion

The discharge spring measurement results were 15 $dm^3 \cdot s^{-1}$ in November 2023 and 14 $dm^3 \cdot s^{-1}$ in February 2024. All physiochemical parameters were within the standard permissible limit. The value of specific EC was 0.0359 $S \cdot m^{-1}$ in the first measurement series, and 0.0421 $S \cdot m^{-1}$ in the second series. The water falls into the medium saline category (Kadhem 2013). The pH values measured during the field tests were 6.95 and 7.13, respectively, which classifies the water from slightly acidic to slightly alkaline (Pazdro, Kozerski 1990). The water temperature in the spring was 8.7°C in November and 9°C in February, while the air temperature on the day of measurement was 0°C and 8°C, respectively. Taking into account the water temperature, the spring is classified as cold (Stevens et al. 2021).

Among the macroelements, the highest concentrations were recorded in the case of bicarbonates (approximately 200 $mg \cdot dm^{-3}$), the concentration of chlorides was on average 20 $mg \cdot dm^{-3}$ and sulphates – 20 $mg \cdot dm^{-3}$. Among the cations, the highest concentrations were observed for calcium – about 80 $mg \cdot dm^{-3}$, followed by sodium – about 11 $mg \cdot dm^{-3}$. The concentration of magnesium was about 1.6 $mg \cdot dm^{-3}$ and potassium about 0.5 $mg \cdot dm^{-3}$. Concerning inorganic nitrogen compounds, the highest concentration was observed for nitrates (about 13.5 $mg \cdot dm^{-3}$), while for ammonium ions and nitrites the concentration was at the limit of quantification in both series of measurements. Half of these values were taken into account, that is, 0.065 $mg \cdot dm^{-3}$ and 0.033 $mg \cdot dm^{-3}$, respectively. The average iron concentration was 0.02 $mg \cdot dm^{-3}$. Among the microelements, only the concentrations of zinc and mercury differed from the limit of quantification. In the first case, the average of two series of measurements was 0.009 $mg \cdot dm^{-3}$ and in the second case it was 0.00009 $mg \cdot dm^{-3}$.

In the case of bacteria, no *Enterococci*, *C. perfringens* or *P. aeruginosa* were observed. *E. coli* was equal to 9 cfu $\cdot$ 100 mL^{-1} in the second series of measurements. Increased values were recorded for two indicators: the total number of microorganisms at 22 ± 2°C and the total number of microorganisms at 36 ± 2°C. The results of the laboratory tests are shown in Table 1.

The results of chemical analyses confirm that the water is of good quality. The waters of this spring are of the bicarbonate-calcium type based on the Shchukaryev–Priklonski classification (Macioszczyk 1987). The percentage composition of dominant ions in the first measurement series was as follows: HCO_3^- (84.34%), Cl^- (8.41%), Ca^{2+} (89.03%), and in the second series HCO_3^- (81.49%), Cl^- (9.89%), Ca^{2+} (83.73%), Na^+ (11.56%). The values of sodium-potassium-chloride, sodium-potassium-magnesium-chloride and calcium-strontium hydrochemical indicators were, respectively, 0.70, 0.89 and 1408. This proves that the spring waters are not in contact with atmospheric waters. Additionally, the high value of the last weight index for calcium and strontium ions confirms the significant role of carbonate rocks in forming the chemical composition of the spring waters.

All physicochemical parameters meet the standards for drinking water in the case of national standards. However, if the EC values were related to WHO recommendations, in the case of the second measurement series the value exceeds the norm (0.0400 $S \cdot m^{-1}$). Some of the parameters such as aluminium, manganese, nickel, cadmium, copper, lead, chromium, Kjeldahl nitrogen, nitrites, ammonium ion and total organic carbon had contents below the limit of quantification. In Table 1, the values of these parameters are marked in italic font. Half of the quantification limit value was to be used for further analysis. Such good results of the quality of water contained in the spring in relation to the standards for drinking water and WHO standards mean that the Contamination Backman Index results were −13.80 and −13.43. For comparison, in the area of pollution sources, the values of this index may be >1000 (Karkocha 2021, Knopek, Dąbrowska 2021).

Referring the obtained results of chemical analyses to the standards for the first quality class, exceedances can be observed for calcium, bicarbonates and nitrates. In the case of the first ingredient, its deficiency in the body is much less beneficial than its excess. The increased concentration of nitrates in water poses a much greater danger. High levels of nitrate in water are a human health concern in the context that nitrate is classified as a probable human carcinogen (Darvishmotevalli et al. 2019). Despite the fact that the limit of nitrates in drinking water is set at 50 mg · dm^{-3} (in the Polish regulation and by WHO standards), it should be noted that in various countries it is often lowered to 10 mg · dm^{-3}, as for first-class water quality.

The situation is slightly different in the case of the bacteriological condition. Based on WHO-recommended and national standards, exceedances include the total number of microorganisms at 22 ± 2°C, *E. coli* and the total number of

Table 1. Water quality results.

Parameter	Unit	Nov 2023	Feb 2024	Relative difference RD	Standard deviation SD	Standard error SE	Limit[1]	Limit[2]	Limit[3]
				[%]		[%]			
Electrolytic conductivity EC	S · m^{-1}	0.0359	0.0221	15.89	0.0043.84	31.00	2500	700	400
pH	[–]	7.13	6.95	2.56	0.13	0.09	6.5–8.5	6.5–8.5	6.5–8.5
Ca^{2+}	mg · dm^{-3}	81	82	0	2.33	1.65	80	50	
Mg^{2+}	mg · dm^{-3}	0.73	2.6	112.31	1.32	0.94	125	30	
Na^{+}	mg · dm^{-3}	9.7	13	29.07	0.00	0.00	200	60	
K^{+}	mg · dm^{-3}	0.5	0.5	0	0.00	0.00		10	
HCO_3^-	mg · dm^{-3}	198	201	1.50	2.12	1.50		200	
SO_4^{2-}	mg · dm^{-3}	16	23	35.90	4.95	3.50	250	60	
Cl^-	mg · dm^{-3}	23	28	19.61	3.54	2.50	250	60	200
NO_3^-	mg · dm^{-3}	14	13	7.41	0.71	0.50	50	10	50
NO_2^-	mg · dm^{-3}	*0.033*	*0.033*	0	0.00	0.00	0.5	0.03	3
NH_4^+	mg · dm^{-3}	*0.065*	*0.065*	0	0.00	0.00	0.5	0.5	
PO_4^{3-}	mg · dm^{-3}	0.081	0.068	17.45	0.01	0.01		0.5	
Fe^{2+}	mg · dm^{-3}	0.002	0.041	181.40	0.03	0.02	0.2	0.2	
Al^{3+}	mg · dm^{-3}	*0.005*	*0.005*	0	0.00	0.00	0.2	0.1	
Mn^{2+}	mg · dm^{-3}	*0.0005*	*0.0005*	163.64	0.00	0.00	0.05	0.05	0.4
Ni^{2+}	mg · dm^{-3}	*0.002*	*0.002*	0	0.00	0.00	0.002	0.005	0.07
Cu^{2+}	mg · dm^{-3}	*0.002*	*0.002*	0	0.00	0.00		0.01	2
Sr^{2+}	mg · dm^{-3}	0.044	0.071	46.96	0.02	0.01			
Pb^{2+}	mg · dm^{-3}	0.002	0.002	0	0.00	0.00	0.01	0.01	0.01
Cd^{2+}	mg · dm^{-3}	*0.00025*	*0.00025*	0	0.00	0.00	0.005	0.001	0.003
Cr^{6+}	mg · dm^{-3}	*0.0015*	*0.0015*	0	0.00	0.00	0.05	0.01	0.05
Hg^{2+}	mg · dm^{-3}	0.00005	0.00013	88.89	0.00	0.00	0.001	0.001	0.006
Zn^{2+}	mg · dm^{-3}	0.0025	0.016	145.95	0.01	0.01		0.05	
S^{2-}	mg · dm^{-3}	4.3	5	15.05	0.49	0.35			
Kjeldahl nitrogen	mg · dm^{-3}	*2.5*	*2.5*	0	0.00	0.00			1.5
TOC	mg · dm^{-3}	*1*	*1*	0	0.00	0.00		5	
Alkalinity	mg · dm^{-3} $CaCO_3$	162	164	1.23	1.41	1.00		–	
Coliform bacteria	cfu · 100 mL^{-1}	0	0	0	0.00	0.00	0	–	0
Escherichia coli	cfu · 100 mL^{-1}	0	9	200	6.36	4.50	0	–	0
Enterococci	cfu · 100 mL^{-1}	0	0	0	0.00	0.00	0	–	0
Clostridium perfringens	cfu · 100 mL^{-1}	0	0	0	0.00	0.00	0	–	0
Microorganisms at 22 ± **2**°C	cfu · mL^{-1}	>300	70	124.32	162.63	115.00	100	–	100
Pseudomonas aeruginosa	cfu · 100 mL^{-1}	0	0	0	0.00	0.00	0	–	0
Microorganisms at 36 ± **2**°C	cfu · mL^{-1}	13	12	8	0.71	0.50	20	–	20

[1]Regulation of the Minister of Health of 07 December 2017 on the quality of water intended for human consumption.
[2]Regulation of the Minister of Maritime Economy and Inland Navigation of 11 October 2019 on the criteria and method of assessing the status of groundwater bodies.
[3]The Guidelines for drinking-water quality (GDWQ) proposed by WHO (2022), Harichandan et al. (2017).
* Italic font suggests half the value of the limit of quantification of a given parameter.

microorganisms at 36 ± 2°C. In the first measurement series, the total number of microorganisms at 22 ± 2°C was over 300 cfu · mL^{-1}. This is an indicator of the total number of bacteria cultured at 22°C for 72 h. These are psychrophilic organisms that die <0°C and >30°C, and develop best at 15°C. They are considered not to be a threat if their number does not >100. The total number of microorganisms in water at 36°C was also different from zero. This is an indicator of the total number of bacteria cultured at 36°C for 48 h. These are mesophilic organisms for which the optimal temperature for growth and development is between 30°C and 40°C. They may include pathogenic bacteria, because the optimal temperature is the same as the human body. It is considered that there is no danger of disease if the number of these bacteria does not >50 in 1 mL of water. Although the amounts of bacteria measured in the samples did not exceed the permissible standard, attention should be paid to this parameter in further measurements.

Faecal contamination of waters resulting from the discharge of raw sewage is a serious problem for human health and the environment (Arvizu, Murray 2021). Such contamination is evidenced by the presence of *E. coli* in water. In the second measurement series, the content of this indicator was 9 cfu · 100 mL^{-1}. An increased number of bacteria in water (even if it is recorded at a medium risk level) can lead to numerous diseases. *E. coli* most often leads to digestive system problems, but in people with weakened immunity it can lead to urosepsis, bacteraemia, meningitis and peritonitis (among others), with potentially severe outcomes including sepsis and death (Biran, Ron 2018, Hernandez-Pastor et al. 2023). Observations of this indicator are particularly important for springs from which water is collected, because *E. coli* can acquire resistance features through chromosomal mutations and mobile genetic elements (Petty et al. 2014).

Summary and conclusions

Springs located in close proximity to buildings or communication networks may be vulnerable to anthropogenic pressures due to inorganic contaminants or bacteriological threats. The results of physicochemical tests for the spring in Złoty Potok did not confirm an increased concentration of the measured parameters, which results from the exceptionally low value of the Contamination Index, but indicated the possibility of bacterial migration into the water. Bacteriological tests should be conducted for this type of water more often due to the possibility of drinking spring water, which in turn may lead to diseases and health hazards. This is especially important in the area of such a spring, which is located in a Natura 2000 area and should additionally be located in a non-threatened area.

The next step in the research will be periodic monitoring observation of selected water quality indicators, and trend analysis of changes in the quality of these waters.

Acknowledgments

The authors thank the reviewers for their insightful comments on the original version of the article.

Author's contribution

D.D., M.R. – conceptualisation, D.D. – methodology, D.D. – software, D.D., M.R. – formal analysis, D.D. – investigation, D.D. – data curation, D.D., M.R., J.W. – writing – original draft preparation, D.D. – writing – review and editing, D.D., J.W. – visualisation. The authors declare no conflict of interest in this study. All authors have read and agreed to the published version of the manuscript.

References

Ansari M.A., Deodhar A., Kumar U.S., Khatti V.S., 2015. Water quality of few springs in outer Himalayas – A study on the groundwater–bedrock interactions and hydrochemical evolution. *Groundwater for Sustainable Development* 1(1–2): 59–67. DOI 10.1016/j.gsd.2016.01.002.

Arvizu I.S., Murray S.R., 2021. A simple, quantitative assay for the detection of viable but non-culturable (VBNC) bacteria. *STAR Protocols* 2(3): 100738. DOI 10.1016/j.xpro.2021.100738.

Backman B., Bodiš D., Lahermo P., Rapant S., Tarvainen T., 1998. Application of a groundwater contamination index in Finland and Slovakia. *Environmental Geology* 36(1–2): 55–64. DOI 10.1007/s002540050320.

Benson C.H., Ören A.H., Gates W.P., 2010. Hydraulic conductivity of two geosynthetic clay liners permeated with a hyperalkaline solution. *Geotextiles and Geomembranes* 28(2): 206–218. DOI 10.1016/j.geotexmem.2009.10.002.

Biran D., Ron EZ., 2018. Extraintestinal pathogenic *Escherichia coli*. *Current Topics in Microbiology and Immunology* 416: 149–161.

Darvishmotevalli M., Moradnia M., Noorisepehr M., Fatehizadeh A., Fadaei S., Mohammadi H., Salari M., Jamali H.A., Daniali S.S., 2019. Evaluation of carcinogenic risks related to nitrate exposure in drinking water in Iran. *MethodsX* 6: 1716–1727. DOI 10.1016/j.mex.2019.07.008.

Gascoyne M., 2004. Hydrogeochemistry, groundwater ages and sources of salts in a granitic batholith on the Canadian Shield, southeastern Manitoba. *Applied Geochemistry* 19(4): 519–560. DOI 10.1016/s0883-2927(03)00155-0.

Gogu R.C., Dassargues A., 2000. Current trends and future challenges in groundwater vulnerability assessment using overlay and index methods. *Environmental Geology* 39(6): 549–559. DOI 10.1007/s002540050466.

Gothwal R., Shashidhar T., 2014. Antibiotic pollution in the environment: a review. *Clean* 43(4): 479–489. DOI 10.1002/clen.201300989.

Guo Y., Li P., He X., Wang L., 2022. Groundwater quality in and around a landfill in northwest China: characteristic pollutant identification, health risk assessment, and controlling factor analysis. *Exposure and Health* 14(4): 885–901. DOI 10.1007/s12403-022-00464-6.

Hamed Y., Hadji R., Ahmadi R., Ayadi Y., Shuhab K., Pulido-Bosch A., 2023. Hydrogeological investigation of karst aquifers using an integrated geomorphological, geochemical, GIS, and remote sensing techniques (Southern Mediterranean Basin—Tunisia). *Environment, Development and Sustainability* 26: 6943–6975. DOI 10.1007/s10668-023-02994-8.

Harichandan A., Sekhar Patra H., Mohan Sethy K., 2017. Evaluation of water quality of local streams at Gandhamardan iron mines, Suakati, Keonjhar District of Odisha, India. *Journal of Pollution Effects and Control* 05(03). DOI 10.4172/2375-4397.1000199.

Heliasz Z., Ptak B., Więckowski R., Zieliński T., 1987. *Explanation to detailed geological map of Poland, sheet Janów (846) 1:50000*. Wydawnictwa Geologiczne, Warszawa.

Hernandez-Pastor L., Geurtsen J., Baugh B., Khoury A.C.E., Kalu N., Gauthier-Loiselle M., Bungay R., Cloutier M., Sarnecki M., Saade E., 2023. Clinical burden of invasive *Escherichia coli* disease among older adult patients treated in hospitals in the United States. *BMC Infectious Diseases* 23(1): 550. DOI 10.1186/s12879-023-08479-3.

Humphrey C.P., Sanderford C., Iverson G., 2018. Concentrations and exports of fecal indicator bacteria in watersheds with varying densities of onsite wastewater systems. *Water, Air and Soil Pollution/Water, Air & Soil Pollution* 229(8): 277. DOI 10.1007/s11270-018-3929-4.

Iverson G., Sanderford C., Humphrey C.P., Etheridge J.R., Kelley T., 2020. Fecal indicator bacteria transport from watersheds with differing wastewater technologies and septic system densities. *Applied Sciences* 10(18): 6525. DOI 10.3390/app10186525.

Kadhem A.J., 2013. Assessment of water quality in Tigris River-Iraq by using GIS mapping. *Natural Resources* 04(06): 441–448. DOI 10.4236/nr.2013.46054.

Karkocha R., 2021. Assessment of changes in the quality of groundwater in the region of the municipal landfill in Wojkowice. *Acta Scientiarum Polonorum. Formatio Circumiectus* 20(1): 43–54. DOI 10.15576/asp.fc/2021.20.1.43.

Kayastha S.P., 2015. Geochemical parameters of water quality of Karra River, Hetauda Industrial Area, Central Nepal. *Journal of Institute of Science and Technology* 20(2): 31–36. DOI 10.3126/jist.v20i2.13945.

Knopek T., Dąbrowska D., 2021. The use of the contamination index and the LWPI index to assess the quality of groundwater in the area of a municipal waste landfill. *Toxics* 9(3): 66. DOI 10.3390/toxics9030066.

Kondracki J., 2000. *Geografia regionalna Polski*. PWN, Warszawa.

Kumar M., Ramanathan A., Tripathi R., Farswan S., Kumar D., Bhattacharya P., 2017. A study of trace element contamination using multivariate statistical techniques and health risk assessment in groundwater of Chhaprola Industrial Area, Gautam Buddha Nagar, Uttar Pradesh, India. *Chemosphere* 166: 135–145. DOI 10.1016/j.chemosphere.2016.09.086.

Macioszczyk A., 1987. *Hydrogeochemia*. Wydawnictwa Geologiczne, Warsaw: 475.

Meng Q., Zhang J., Zhang Z., Wu T., 2016. Geochemistry of dissolved trace elements and heavy metals in the Dan River Drainage (China): distribution, sources, and water quality assessment. *Environmental Science and Pollution Research International* 23(8): 8091–8103. DOI 10.1007/s11356-016-6074-x.

MIiR [Ministerstwo Inwestycji i Rozwoju], 2019. Dane do obliczeń energetycznych budynków. Online: www.gov.pl/web/archiwum-inwestycje-rozwoj/dane-do-obliczen-energetycznych-budynkow (accessed 6 August 2024).

Muhammad S., Shah M.T., Khan S., 2011. Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan. *Microchemical Journal* 98(2): 334–343. DOI 10.1016/j.microc.2011.03.003.

Online: https://www.gov.pl/web/archiwum-inwestycje-rozwoj/dane-do-obliczen-energetycznych-budynkow (accessed 16 June 2024).

Owamah I., Asiagwu A., Egboh S., Phil-Usiayo S., 2013. Drinking water quality at Isoko North communities of the Niger Delta Region, Nigeria. *Toxicology and Environmental Chemistry/Toxicological and Environmental Chemistry Reviews/Toxicological and Environmental Chemistry* 95(7): 1116–1128. DOI 10.1080/02772248.2013.847939.

Pacholewski A., Guzik M., 1997a. Explanations to the hydrogeological map of Poland on a scale of 1:50,000, Janów sheet (846). Polish Geological Institute, Warsaw.

Pacholewski A., Guzik M., 1997b. *Hydrogeological map of Poland on a scale of 1:50,000, Janów sheet (846)*. Polish Geological Institute, Warsaw.

Pazdro Z., Kozerski B., 1990. *Hydrogeologia ogólna*. Wydawnictwa Geologiczne, Warsaw: 624.

Petty N.K., Zakour N.L.B., Stanton-Cook M., Skippington E., Totsika M., Forde B.M., Phan M., Moriel D.G., Peters K.M., Davies M., Rogers B.A., Dougan G., Rodriguez-Baño J., Pascual A., Pitout J.D.D., Upton M., Paterson D.L., Walsh T.R., Schembri M.A., Beatson S.A., 2014. Global dissemination of a multidrug resistant *Escherichia coli* clone. *Proceedings of the National Academy of Sciences of the United States of America* 111(15): 5694–5699. DOI 10.1073/pnas.1322678111.

Pinter I.F., Salomon M.V., Gil R., Mastrantonio L., Bottini R., Piccoli P., 2018. Arsenic and trace elements in soil, water, grapevine and onion in Jáchal, Argentina. *Science of the Total Environment* 615: 1485–1498. DOI 10.1016/j.scitotenv.2017.09.114.

Pokładek R., Kowalczyk T., Orzepowski W., Pulikowski K., 2011. Na, K, Ca and Mg concentrations in effluent water drained from agricultural catchment basins in Lower Silesia. *Journal of Elementology* 16(3): 467–479. DOI 10.5601/jelem.2011.16.3.11.

Regulation of the Minister of Health of 07 December 2017 on the quality of water intended for human consumption (Journal of Laws of 2017, item 2294).

Regulation of the Minister of Maritime Economy and Inland Navigation of 11 October 2019 on the criteria and method of assessing the status of groundwater bodies (Journal of Laws of 2019, item 2148).

Sari M.M., Andarani P., Notodarmojo S., Harryes R.K., Nguyen M.N., Yokota K., Inoue T., 2022. Plastic pollution in the surface water in Jakarta, Indonesia. *Marine Pollution Bulletin* 182: 114023. DOI 10.1016/j.marpolbul.2022.114023.

Stevanović Z., 2010. Utilization and regulation of springs. In: *Groundwater hydrology of springs*: 339–388, Elsevier. DOI 10.1016/b978-1-85617-502-9.00009-8.

Stevens L., Schenk E., Springer A., 2021. Springs ecosystem classification. *Ecological Application* 31(1): 2218. DOI 10.1002/eap.2218.

Tałałaj I.A., 2014. Assessment of groundwater quality near the landfill site using the modified water quality index. *Environmental Monitoring and Assessment* 186(6): 3673–3683. DOI 10.1007/s10661-014-3649-1.

Todd D., 2009. *Groundwater hydrology*. John Wiley & Sons, New Delhi, India.

Willscher S., Mirgorodsky D., Jablonski L., Ollivier D., Merten D., Büchel G., Wittig J., Werner P., 2013. Field scale phytoremediation experiments on a heavy metal and uranium contaminated site, and further utilization of the plant residues. *Hydrometallurgy* 131–132: 46–53. DOI 10.1016/j.hydromet.2012.08.012.

Wojtal A.Z., Okon D., Rózkowski J., 2017. Różnorodność okrzemek (Bacillariophyta) w źródłach okolic Zawiercia. In: *post-conference materials of XXVII Sympozjum Jurajskie*. Człowiek i Przyroda Wyżyny Krakowsko-Wieluńskiej. ZPKWS, Będzin: 67–73.

WHO [World Health Organization], 2022. *Guidelines for drinking-water quality*, 4th edn. World Health Organization, Geneva.

Zembal M., Szulik J., Cudak J., 2013. GIS database of the hydrogeological map of Poland at a scale of 1:50,000. First aquifer, sensitivity to pollution. Janów sheet. Polish Geological Institute, Warsaw.

Zhang Q., Feng M., Hao X., 2018. Application of Nemerow index method and integrated water quality index method in water quality assessment of Zhangze Reservoir, *IOP Conference Series. Earth and Environmental Science* 128: 012160. DOI 10.1088/1755-1315/128/1/012160.