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An attempt to explain the disappearance and decline in discharge rate of selected karst springs of the Opole region

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Significant discharge changes of karst springs, to the point of their disappearance, prompt research into the causes as related both to climate change and to human-induced factors. This analysis uses climate data from the last 70 years, publications from the beginning of the 20th century, biennial measurements of the discharge rate of six selected springs over the last 40 years, and considerations of mine drainage. An increase in average air temperature by 1.5°C in the last 30 years, a slight decrease in precipitation and an almost quadrupled increase in groundwater extraction in mines were recognised. Such a significant increase in mine-related groundwater extraction significantly affects the springs' discharge rate and the river network. Significant mine drainage and groundwater extraction are causing deleterious changes to previously good-quality groundwater.

Key words: springs, karst, discharge change, climate and its variability, mine dewatering, groundwater.

INTRODUCTION AND THE AIM OF THE RESEARCH

The IPCC's Sixth Assessment Report (2021) finds a 1.2–1.5°C increase in the globe's average air temperature in recent years. Simultaneously, the most recent studies from 2021–2022 have shown frequent disappearance and/or a significant decrease in the discharge rate of selected large water sources draining Triassic carbonate rocks in the Opole region (SW Poland) compared to the measurements from the 1980s. This research explores this phenomenon using several-years series of discharge rate measurements of the springs over the last 40 years. This requires an assessment of both natural and anthropogenic factors determining the response of the springs and the current state of groundwater resources. The question is which factors, and to what extent, determine such significant changes in the discharge rate of the springs observed. Is it climate change, involving precipitation and the recorded warming, or is it the exploitation of groundwater resources?

The study area is located in SW Poland and is part of the Kraków-Silesian Upland. The karst springs occurring here drain Triassic limestones and dolomites (Rhoetian and Muschelkalk). The springs are located on the monoclinal unit of the Silesian Upland. In the past, springs draining carbonate rocks reached high discharge rate reaching 330 l/s (Staśko, 1984, 1992). The spring-fed basins constitute mainly agricultural areas with a small proportion of forests and rural and urban developments. In the area researched, there are four large opencast mines, namely Strzelce Opolskie, Tarnów Opolski, Izbicko and Górażdże, which mine limestone and dolomite to produce cement and road aggregate. Exploitation of the limestone involves their dewatering.

RESEARCH METHODS AND COLLECTED DATA

The local karst springs drain Triassic carbonate rocks. The springs are located on the monocline unit of the Silesian Upland. Reservoir rocks comprise Triassic limestones and dolomites of Germanic facies. Above Bunter sandstones, there are dolomites, marls and Roethian evaporites, as well as Muschelkalk rocks 70–90 m thick. The last of these constitute a groundwater resource. Previous research has shown the porosity of the limestones and dolomites are in the range of 0.9–31.9% (12% on average). They are accompanied by fracture and karst phenomena (Staśko, 1992; Kryza and Staśko, 2000). The value of hydraulic conductivity varies, as determined based on pumping tests, in the range between 1.7×10^{-7} and 4.8×10^{-3} m/s (Wcisło et al., 2014). However, a typical value is high, at 4×10^{-4}m/s. The wells exploiting this aquifer provide 100–130 m^3/h with a small depression. The groundwater table shows large changes with the annual amplitude reaching 10.8 m. The flow rate, determined using isotopic constraints, is

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Table 1

Basic information about the sources studied

Spring	Geographic position	Outflow elevation [m a.s.l.]	Observation period	Authors	Discharge average Q [l/s]	Remarks/measurement number
1.Błotnica Strzelecka	50° 29' 54" N, 18° 7' 43" E		1981–1989 1991–1992 2018–2019 2021–2022	S WZ JK STB	58.6 8.3 2.4 16.2	"Thousand springs" /67
2.Rożniątów	50° 30' 27" N 18° 15' 1" E	231.0	1981–1989 1991–1992 2002–2003 2018–2019 2021–2022	S WZ ZA JK STB	130.4 14.8 0.0 0.0 33.3	Areal outflow/114
3.Sucha	50° 33' 09" N 18° 13' 26" E	194.7	1981–1987 1988–1989 2002–2003 2018–2019 2021–2022	S FN ZA JK STB	115.9 5.4 0.0 1.2 4.1	Areal outflow /111
04.Odrowąż	50° 30' 53" N 17° 57' 19" E	157.0	1981–1983 1986–1989 1983–1984 2002–2003 2018–2019 2021–2022	S S RS ZA JK STB	82.8 79.6 63.3 38.36 29.9 67.7	Odra valley/113
5.Gąsiorowice	50° 33' 27" N 18° 21' 31" E	205.8	1991–1992 2018–2019 2021–2022	WZ JK STB	6.51 13.2 34.2	Linear spring/20
6.Poręba	50° 26' 32" N 18° 11' 9" E	235.7	1984–1987 2002–2003 2018–2019 2021–2022	FN ZA JK STB	17.8 23.14 11.7 17.4	"Seven Springs"/113

Authors: S – Stanisław Staśko; JK – Jakub Kacprzak; STB – Stanisław Staśko, Marta Trałka, Marek Błachowicz; FN – Franciszek Nowacki; RS – Roman Śliwka; WZ – Wojciech Zieliński; ZA – Zaleska

10–25 years in the active flow zone. The sources draining the limestones attain high recharges, reaching 330 l/s (Staśko, 1984, 1992). Detailed research of the variability took place in 1980–1983, and was resumed in 2018–2022. In this case, comparisons for the 40-year observation period are possible. The discharge rate of six sources was measured and studied. Out of these, four were subject to detailed weekly observations in 1980–1983 (Staśko, 1984, 1992). These were springs in Rożniątów, Sucha, Błotnica Strzelecka and Odrowąż (Table 1 and Figs. 1 and 2). Studying their variability after 40 years, two additional outflows in Poręba and Gąsiorowice were included in the observation network and measurements were resumed in 2021–2022.

Fig. 1. Location of the research area within Poland

The results of the author's latest research in 2021–2022 were supplemented with measurements by other authors from 1984–1989 for the springs of Odrowąż (Śliwka, 1984), Poręba and Sucha (Nowacki, 1987, 1989a, b) from 1991–1992 for the springs of Błotnica Strzelecka and Rożniątowa (Zieliński, 1992) and 2018–2019 (Kacprzak, 2019). The data from these intervals comprises over 484 measurements. They constitute a basis for the comparison of discharge changes over the last 40 years. The basic parameters of the observed sources and the results of the measurements are summarized in Table 1.

The discharge rates of these large karst springs were measured using calibrated flowmeters: in 1980–1983 with a Hega flowmeter, and in 2021–2022 with a Seba F-1 flowmeter with an accuracy of 2–5%.

To consider the reasons for discharge changes of the sources, the available detailed climate data on precipitation and air temperatures were compiled. Data were collected for the Opole station and the station located in the basin area in Strzelce Opolskie from the period 1951–2022. Archival data were obtained from the database of the Institute of Meteorology

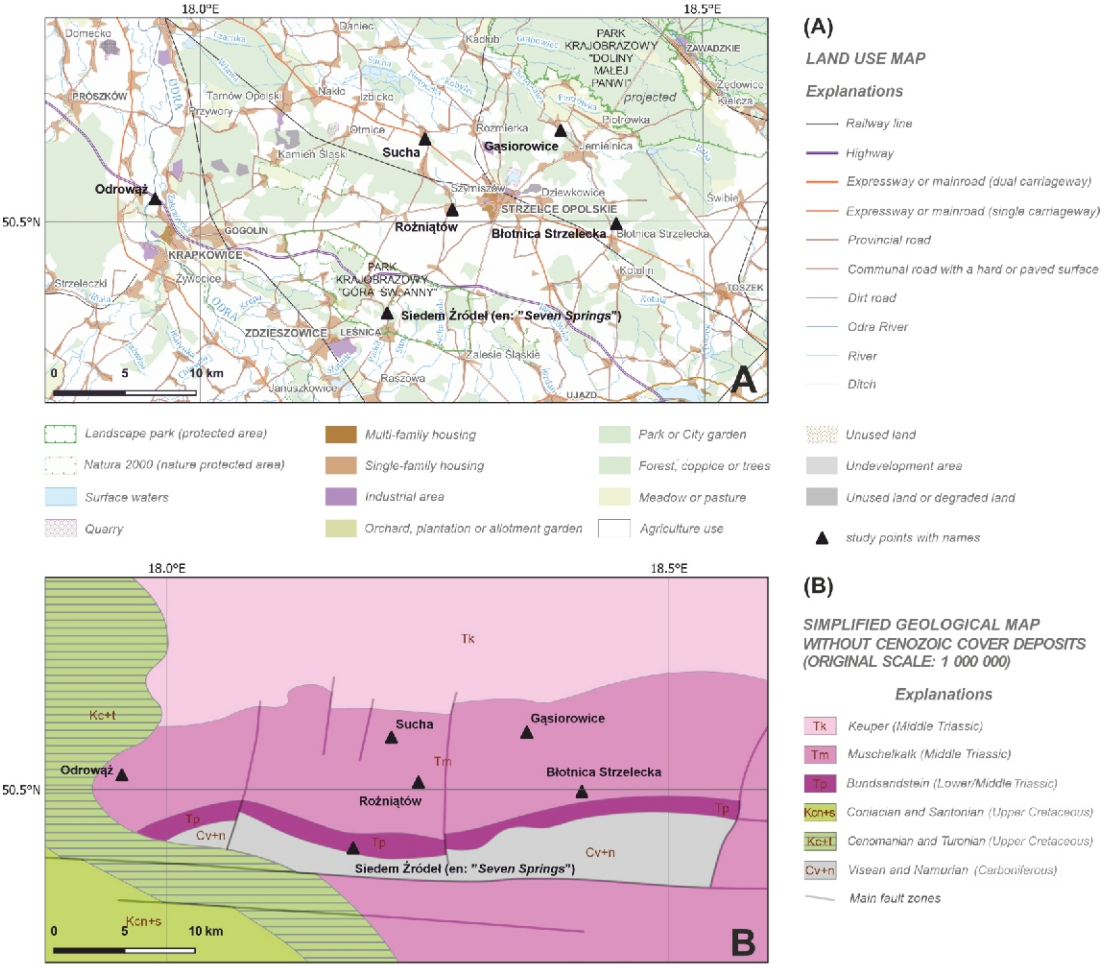

Fig. 2. Research area and monitored springs on a map of land management and simplified geology

and Water Management (IMGW; pogodynka.pl). The measurements were taken using appropriate climate research methodology (of the Institute of Meteorology and Water Management Report). To compare longer time periods, historical precipitation data from 1892–1939 were compiled (Klimatekunde,1939). Subsequently, archival and currently available data on the volume of discharged groundwater from opencast mines in Tarnów Opolski and Strzelce Opolskie were collected (Marshal's Office Opole, PP Wody Polskie, Information System Opole). The results of mine dewatering and continuous climatic measurements collected in this way were used to determine their impact on discharge changes in selected sources.

RESEARCH RESULTS AND DATA ANALYSIS

Four sources draining Triassic limestone rocks were subject to detailed measurements between 1980–1983 and more recently between 2018–2022. Archival measurements from the 1980s allow division of the sources studied into two groups. The first group includes two sources with high discharge rates reaching 330 l/s and the highest variability, with disappearance of the outflow as the minimum. These are the springs in Sucha and Rożniatow, nos. 2 and 3, Table 1 and Figure 1, respectively. The other group includes sources with variable discharge rates, though never disappearing. These are outflows in Odrowąż, Błotnica Strzelecka, Poręba and Gąsiorowice.

The spring in the village of Rożniątów, located to the west of Strzelce Opolskie, flows out in the center of the village and drains the water-bearing top layers of the Roetian, made of limestone and dolomite (Fig. 3).

Fig. 3. Rożniątów spring in March 2022

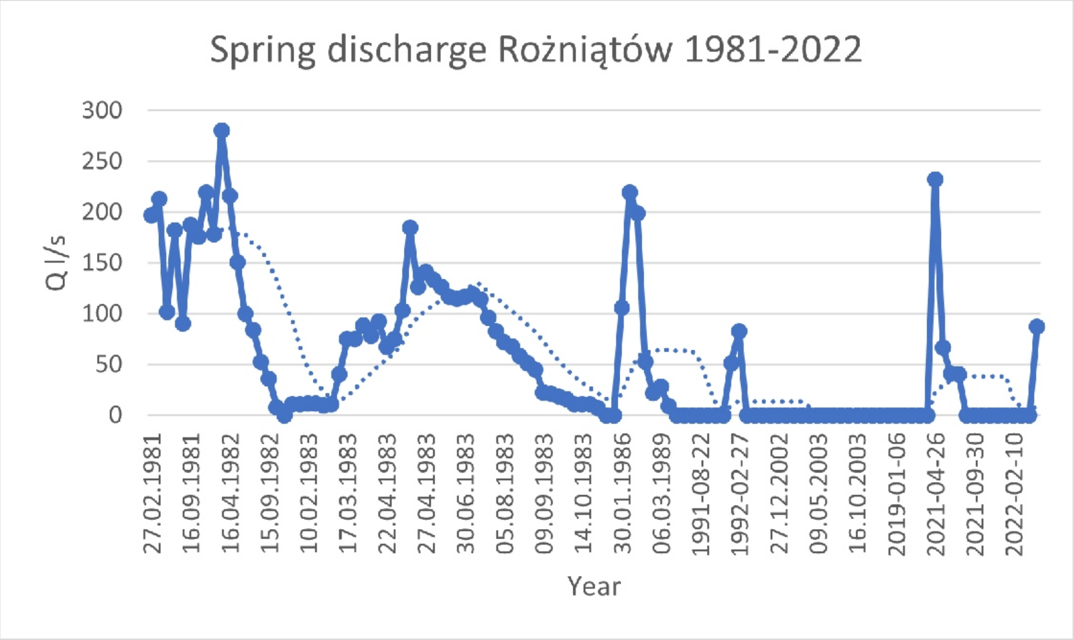

Fig. 4. Discharge change of the spring in Rożniątów from 1981 to 2022

The spring flows from an escarpment and forms a 30 50m pond. It has the longest observations, of more than a century. According to archival data, "the spring was so strong in the last century that it powered a water mill" and "only in the exceptionally dry years of 1914, 1921 and 1928 was there a visible weakening of the spring" and "The water resources are so great that they can be described as almost inexhaustible" Assmann (1929). The most recent surveys found the water outflow of the Rożniątów spring to be only from April to July 2021 and in October 2022. During the remaining parts of 2002–2003, 2018–2019 and 2021–2022, no water came from the spring. Changes in the discharge rate of this spring in the periods observed are shown in Figure 4.

There has been a downward trend in average discharge rates and long periods of water shortages in recent years. The dashed line indicates moving average 10 points values.

Beyond the village of Szymiszów, the waters of the Rożniątów stream disappear into a ponor (Fig.5). However, three kilometres away, another large spring was found in the village of Sucha. It is located in a meadow 200 metres from the Strzelce Opolskie-Opole Road and flows out of Muschelkalk carbonate rocks that overlie the Roetian strata (Fig. 6).

Studies from the 1980s showed high discharge rates in the range of 11-332 l/s, including discharge rates of above 100 l/s which were recorded for 15 months. In 1981–1983, the average discharge rate was 115.9 l/s. However, like the Rożniątów spring, outflow disappearances were noted for three months from November 1982 to February 1983. Surveys in 2021–2022 showed a significant, over 10-fold, decrease in discharge rate. Outflow from this source was observed for only three months from April to June 2021.

As in the case of the Rożniątów spring, the variable and periodic spring in Sucha has recently shown significant changes and long-term water shortages since 1988. This is shown in Figures 7 and 8.

The spring in Błotnica Strzelecka (also described as the Centawa or Thousand Springs in other papers) is located in a valley south of the school building on the edge of the forest, 800 m from the Strzelce Opolskie-Gliwice Road. It constitutes an extensive spring with 14 distinct artesian, pulsating outflows. It was labelled as the site of the "Thousand Springs" on older geologic maps (Assmann, 1944) and drains Roetian reservoir rocks (Fig. 9).

Fig. 5. Dry spring, Rożniątów, January 2020

Fig. 6. Sucha spring May 1982

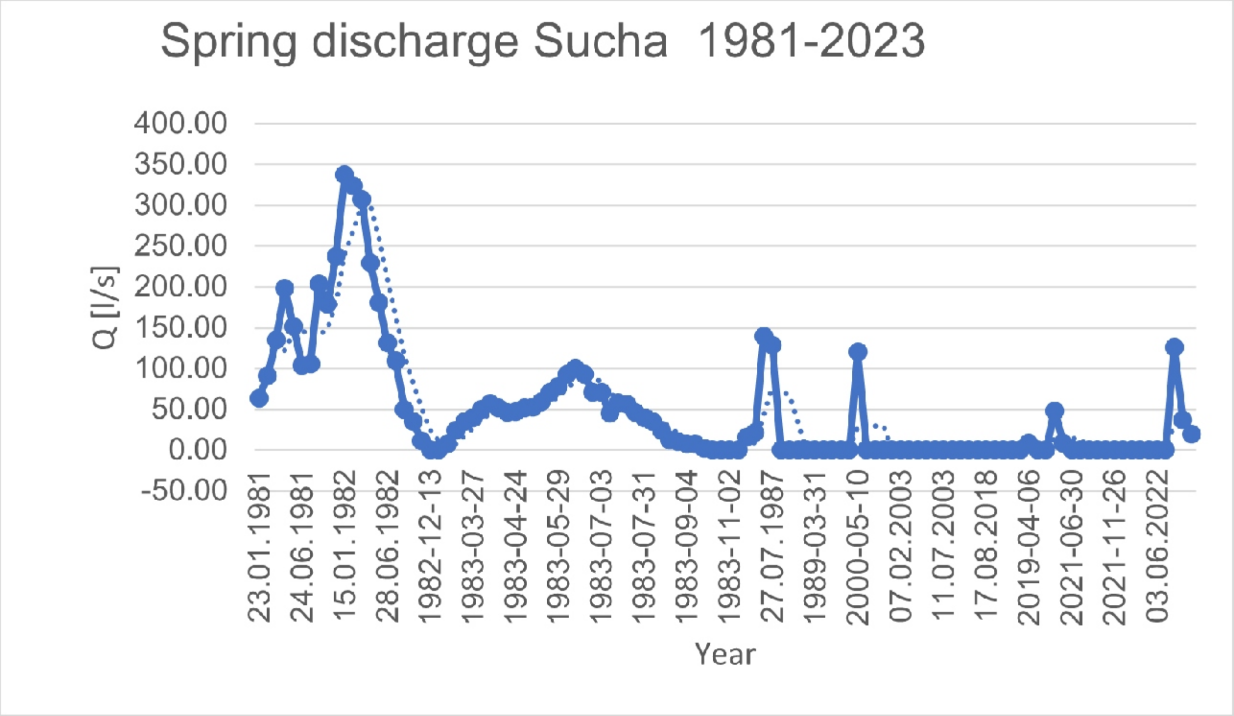

Fig. 7. Discharge changes in the Sucha spring from 1981 to 2022

In the 1980s, the spring in Błotnica Strzelecka (Fig. 11) showed an average discharge rate of 53 l/s (Staśko, 1988). Currently, based on observations in 2021–2022, it shows a two-thirds lower value on average, namely 16.9 l/s. For a good part of the year, from September to March, low discharge rates of 1–5 l/s and short periods of disappearance were noted, as shown in Figure 10.

The spring in Odrowąż is located on the terrace of the Odra River just below the bridge over the Odra River on the A4 motorway route and drains Muschelkalk rocks. It has now been turned into a trout fishery (Figs. 12 and 14) and is a specific site for unusual plant species (Spałek et al., 2011). Measurements of the discharge rate of this spring in the 1980s were at 82-63 l/s while today average discharge rates of 67–29 l/s are observed (see Fig. 13).

In turn, the spring in Poręba is in the stream valley near the road from St. Anne's Mountain on the south side of this mountain. It drains Roetian limestones and dolomites (Fig. 15). Historical records show that there were several water mills here in the last century. According to the data for the 1980s, the discharge rates noted were 11–17 l/s, and currently the average rate is 14.9 l/s (Fig. 16).

The spring in Gąsiorowice is located north of Strzelce Opolskie and the Strzelce Opolskie limestone mine (Fig. 17). It flows out of an escarpment near the road and drains the top Muschelkalk rocks. In 1991–1992 the spring showed variable discharge rates between 0–32 l/s (Zielinski, 1992). In 2018–2002, discharge rates were 17–34 l/s (Fig. 18). More recent measurements, however, show an average of more than 30 l/s.

Fig. 8. Dry outflow spot, the Sucha spring, March 2022

Fig. 9. Spring in Błotnica Strzelecka (Centawa), called the Thousand Springs, in May 1982.

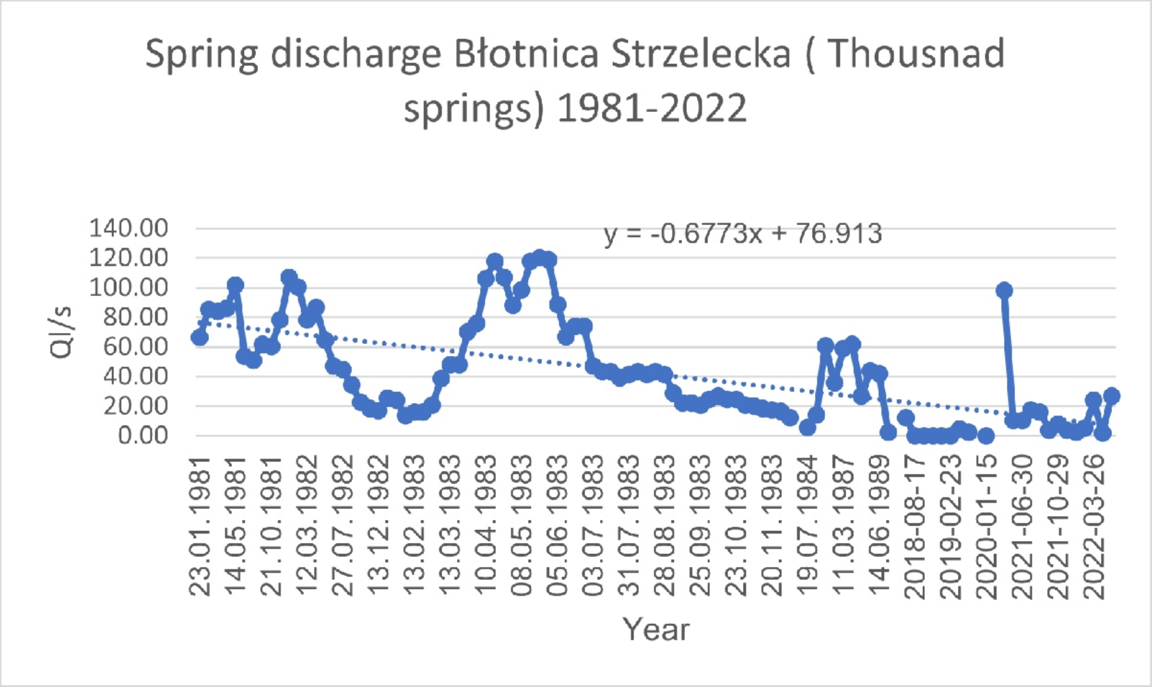

Fig. 10. Discharge rate of the spring in Błotnica Strzelecka in 1981–2022

CLIMATE AND ITS CHANGES IN THE RESEARCH AREA

The Opole region is one of the warmer regions in Poland. The average air temperature for the city of Opole was 8.55°C during the last half of the 20th century (1950–1999). However, for the period 2000–2020, an increase of up to 9.84°C has been recorded (IMGW Data base). The graph shows a clear rising trend in the last two decades.

Average annual air temperatures have undergone periodic changes and show an upward trend in the last 30 years. To determine the trend for these changes, deviations from the average for a typical 30-year period covering 1980–2010 were calculated in accordance with the recommendations of the of IMGW (Climate of Poland, 2021). During the 70-year period analysed, air temperatures have shown significant deviations from the average normal temperature.

As shown in Figure 19, there is an upward trend which is particularly clear since 1989 with a maximum in 2001–2020. It is preceded by a long period of temperature deviations with negative values. A cold period with deviations of –2.39°C and –1.79°C (1956 and 1963) was recorded from 1955 to 1982.

Thus, we deal with an example of sinusoidal changes in annual average temperatures, influenced by several factors. A comparison with the temperature graph (Fig. 20) suggests a cyclicity of air temperature changes in this area. In addition to the trend of increasing temperatures, cooler periods have also been noted. This is corroborated by IMGW observations show-

Fig. 11. No outflow of the spring in Błotnica Strzelecka January 2020

Fig. 12. The spring in Odrowąż in May 1982

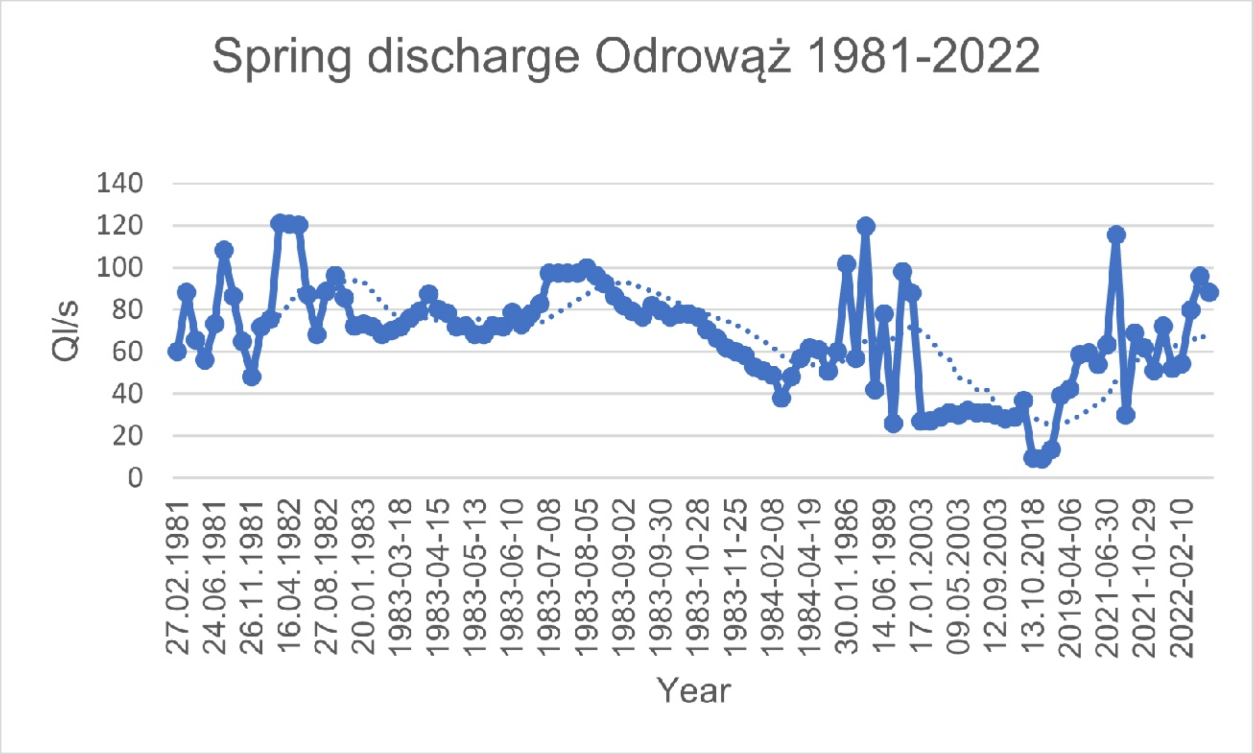

Fig. 13. Discharge rate of the spring in Odrowąż in 1981–2022

ing that cold periods with deviations in annual average temperature reaching –2°C were recorded in the period 1950–2000 and a recent warm period in 2000–2020 (Climate of Poland, 2021). This illustrates the sinusoidal changes in temperatures for the long period analysed. Interestingly, the topographically higher Strzelce Opolskie station shows lower air temperatures by ~1°C.

The second major factor determining the size of groundwater resources is precipitation. Average annual precipitation for the two stations around Opole and Strzelce Opolskie in the past as well as the present is summarized below.

Typical yearly distributions of monthly precipitation totals are summarized for the years 1892–1939 (Klimatekunde, 1939) and more recent measurements from 1951–2022 for the Opole and Strzelce Opolskie stations as shown in Figure 21.

This is a typical distribution of monthly precipitation values for the continental areas of central Europe, with one maximum value (100–110 mm) falling in the month of July. In the months preceding May-June and in September, the totals revolve around the range of 50–80 mm. In the remaining months they have lower values of 30–50 mm. Higher monthly totals are evi-

Fig. 14. The spring in Odrowąż, turned into a trout fishery October 2021

Fig. 15. Poręba (Leśnica) Seven Springs, March 2022

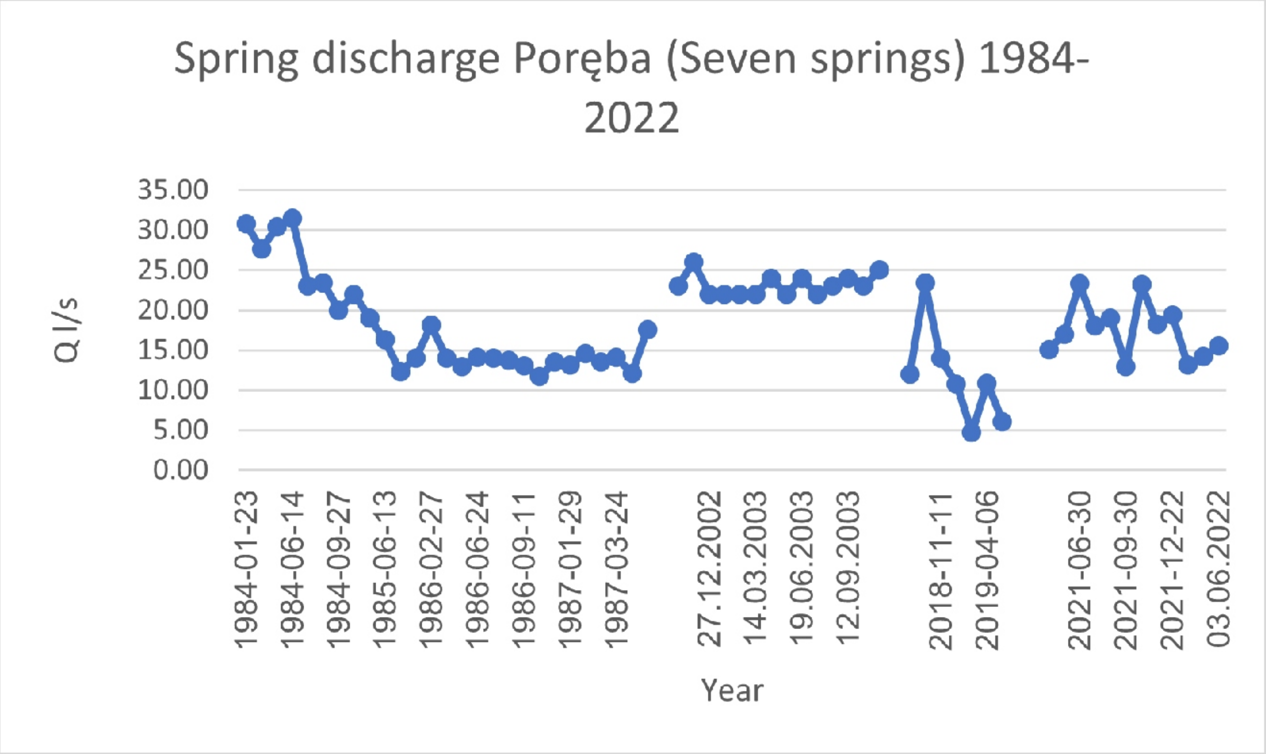

Fig. 16. Discharge rate of the Poręba spring from 1984 to 2022

Fig. 17. Spring in Gąsiorowice April 2021

dent for the Strzelce Opolskie station (altitude effect) and in recent years lower monthly average values have been recorded for the Opole station.

In the first half of the twentieth century, precipitation in Opole was 649 mm (Klimatekunde, 1939). In 1963–1982, an increase of up to 688 mm was noted and currently it is lower at 608.6 mm. Higher annual precipitation is found for Strzelce Opolskie. The values were 721 mm, 782 mm (1963–1982) and currently 696.3 mm, respectively. Archival data from the beginning of the 20th century and current data show a decrease in annual precipitation totals in the Opole area (Fig. 21). The calculated difference in the vicinity of Opole is 6.7–10.4% compared to data from the beginning of the 20th century. However, in the area of Strzelce Opolskie no such large changes are found and the decrease in annual precipitation is negligible at 6%.

The graph shows a general decrease in the average annual precipitation totals against a background of dry years with a negative deviation (e.g., 1951–1955, 1957–1961) or wet years (1964–1968, 1984–1988). The cyclicity of climatic phenomena, e.g. in the distribution of precipitation and temperature, has already been noted and described, e.g. Brückner (1890) and Boryczka (2001) where 5–6, 10–13, 21–24 and 32–36 year-long periods of change have been shown. In turn, measurements around the springs (Strzelce Opolskie) from 1950–2022 show the opposite trend – an increase in precipitation in recent years (Fig. 22). This indicates the influence of local climatic factors.

With the increase in altitude in the Strzelce Opolskie region, the average annual precipitation is 696 mm. In the wet years of 1963–1982 it was higher: 782 mm (Fig. 23). Wet years are visible in the period 1958–1981 and 2009–2010, followed by dry years 1982-2006 and then alternately wet and dry. In addition, noticeably higher than average precipitation was recorded in 1997–2001 and 2020 and 2022.

The weighted average precipitation in previous years was 724 mm for the springs' basin analysed.

GROUNDWATER EXPLOITATION

Available data on mine dewatering were collected for the Tarnów Opolskie mine from 1978–2022 (Kryza and Kryza, 2000; Polish Water Information System) and for the Strzelce Opolskie mine from 2008–2022 (Database of the Marshal's Office and Information System). The Górażdże Company has a water-legal permit from 2007 for the dewatering of the "Strzelce Opolskie" limestone mine to an ordinate groundwater level not exceeding 188.5 m a.s.l. The document specifies the maximum daily discharge of good quality water into the Sucha River at 74,400 m^3/d. Similarly, the Tarnów Opolski mine has a permit

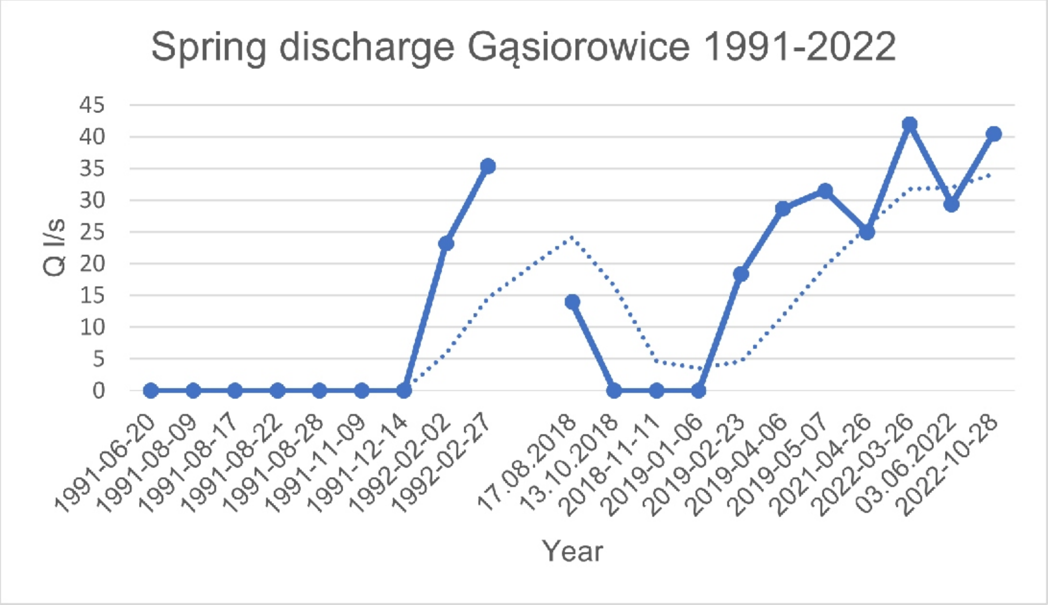

Fig. 18. Discharge changes of the spring in Gąsiorowice in 1991–2022

from 2012 for water intake of 100,000 m^3/d and discharge of 110,000 m^3/d into the Struga River with the long-term lowering of the groundwater table to the ordinate of 152.6 m above sea level. Both companies are required to report their discharges in accordance with the Water Law.

The Tarnów Opolski mine has increased groundwater extraction tenfold over the course of 40 years. Initially, from 1978, it discharged mine water at 8,000 m^3/d. However, since the 1980s there has been a continuous increase from a value of 30,000 m^3/d (1989) to a value of more than 60,000 m^3/d in the 1990s. In 2000–2022, daily averages of 59,000–81,000 m^3/d were reported. The maximum volumes were recorded in 2010 and 2011 – 81,131 and 81,671 m^3/d, respectively (Fig. 24).

In the 21st century, the Strzelce Opolskie mine discharged an average of 25,106 m^3/d of water, which is two to three times less than that from Tarnów Opolski. Based on available published data, groundwater exploitation in the Strzelce Opolskie mine in 1998 was within a similar or slightly lower range and amounted to 14,000 to 24,000 m^3/d (Gnyra, 1998). Twenty years later in 2008–2016, the average value increased and amounted to 25,200 m^3/d. It varied from 19,000 to 36, 0000 m^3/d (Marshal's Office annual archive report) as illustrated in Figure 25.

In total, the two mines discharged between 72,100 m^3/d and 117,000 m^3/d of groundwater between 2010 and 2020.

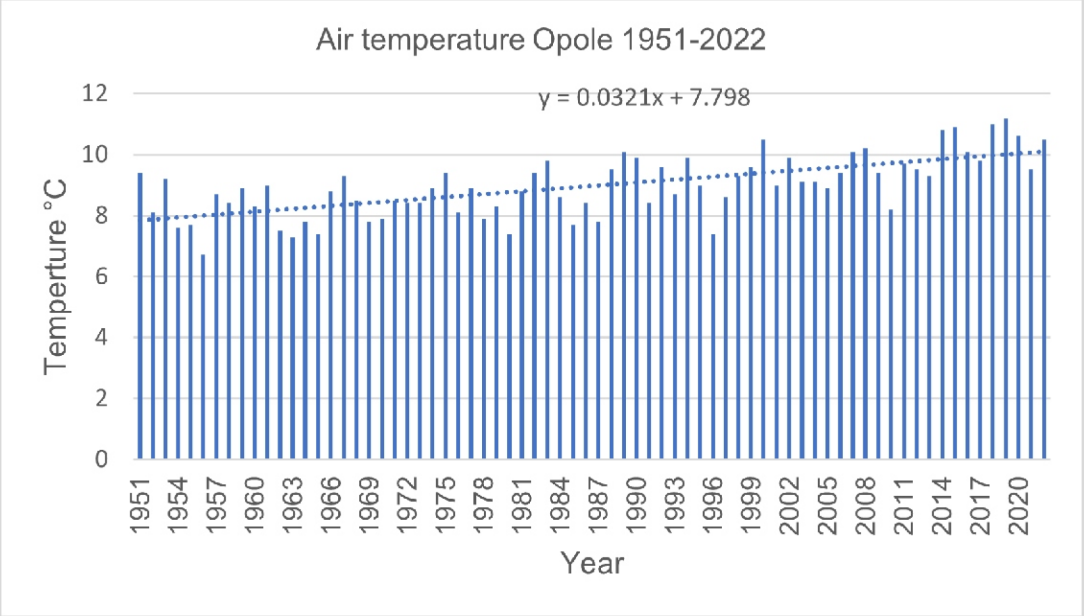

Fig. 19. Average air temperature in Opole from 1951 to 2022

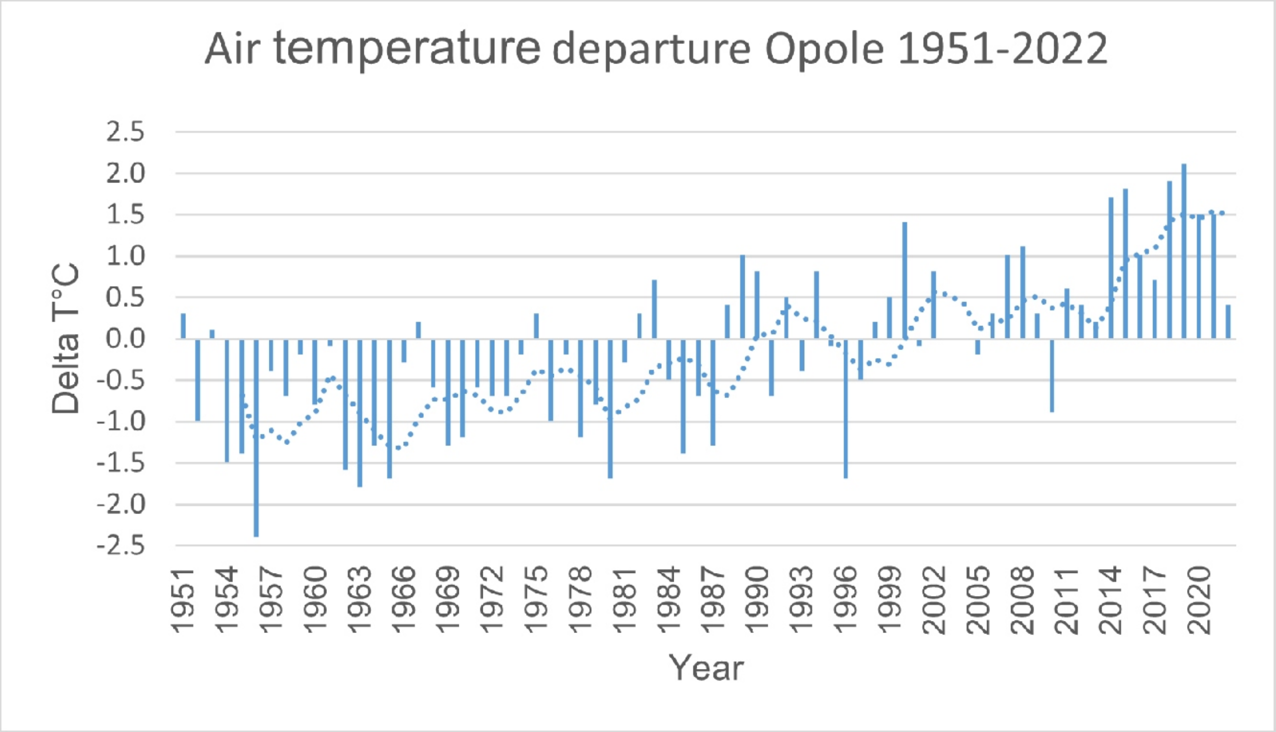

Fig. 20. Deviations of annual average values from the average air temperature between 1951–2020 for Opole

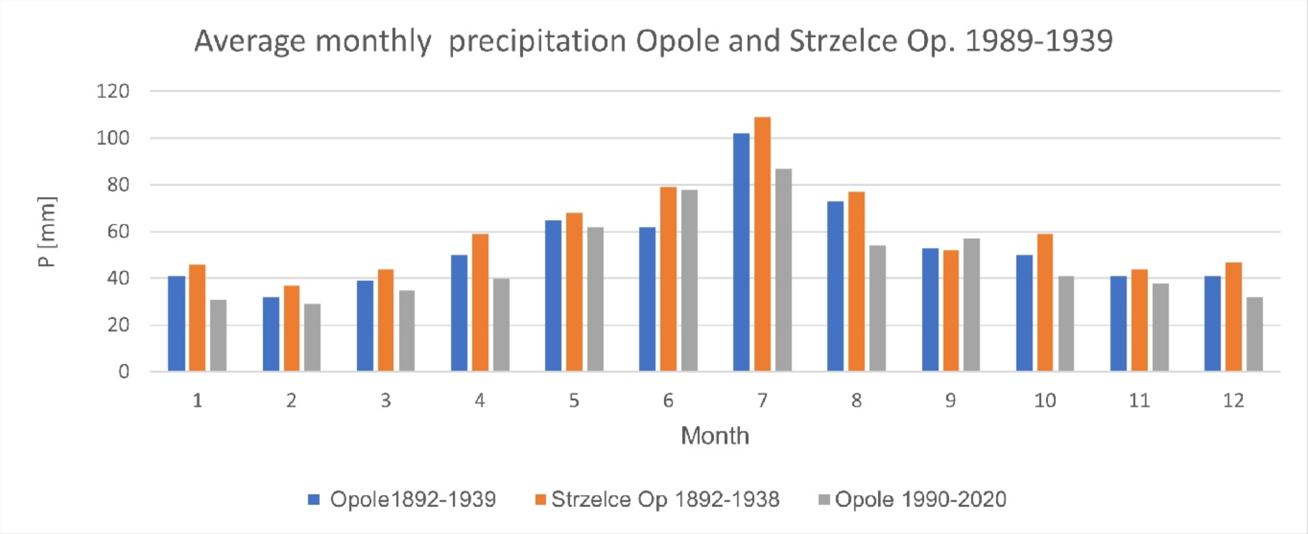

Fig. 21. Average monthly precipitation totals for Opole and Strzelce Opolskie 1892–1939, and Opole 1950–2022

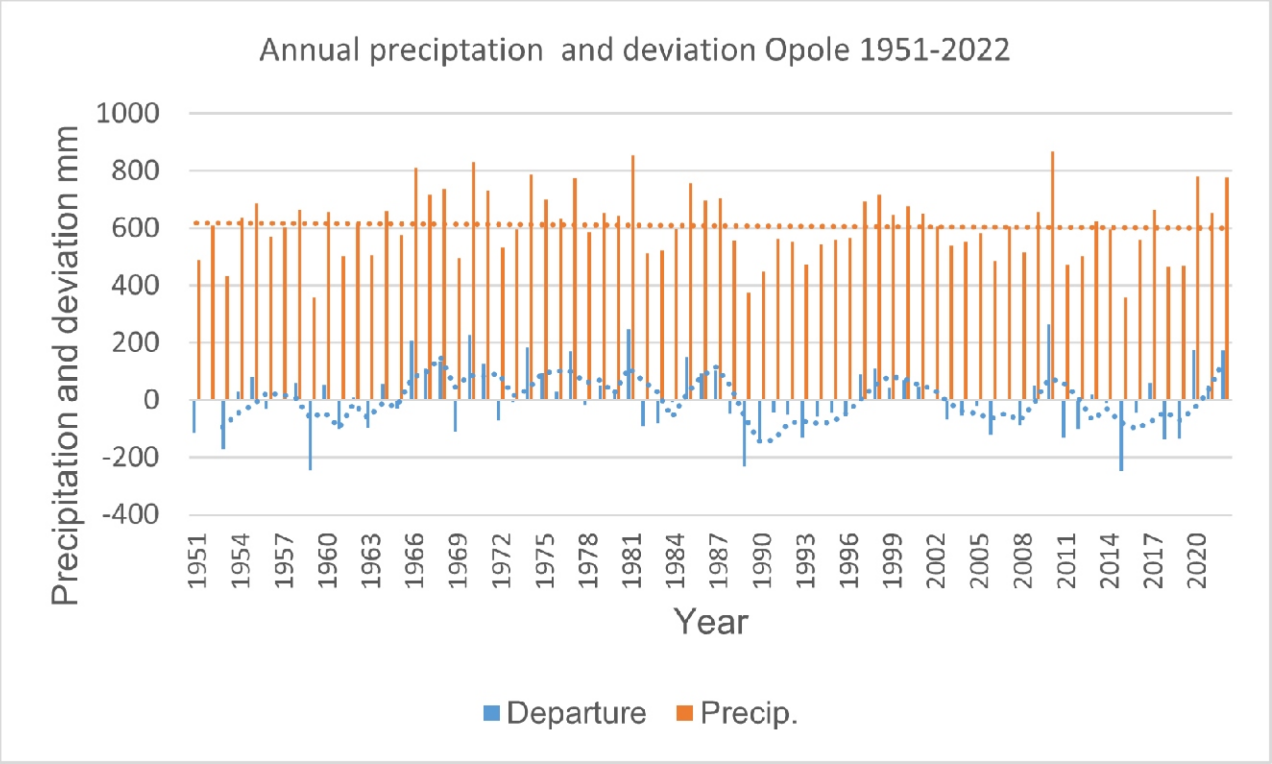

Fig. 22. Average annual precipitation totals for the Opole station and deviations from the averages in 1951–2022

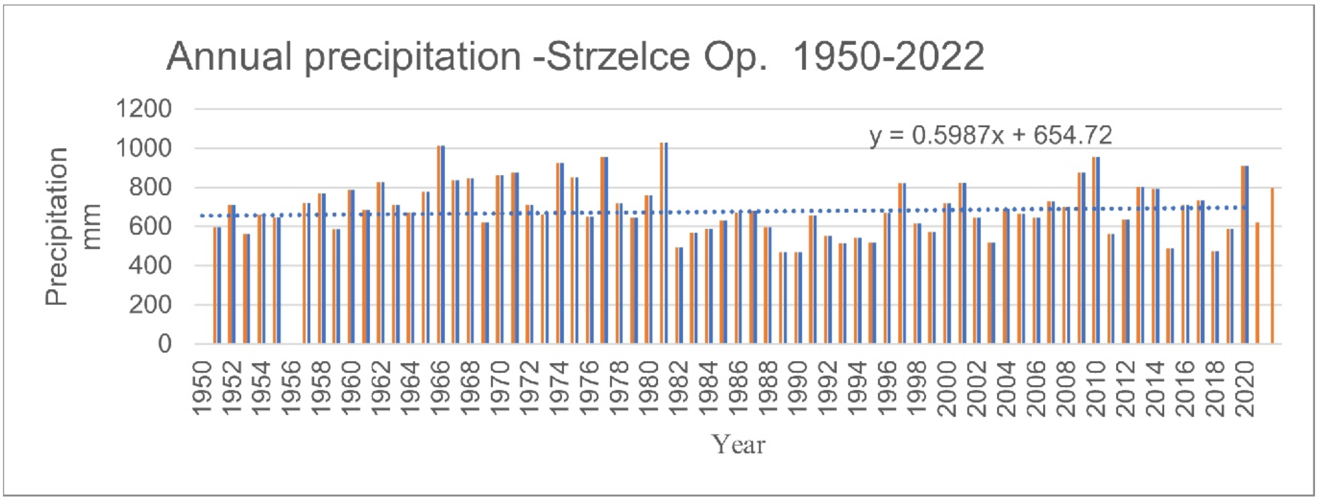

Fig. 23. Annual precipitation totals from 1951–2022, Strzelce Opolskie

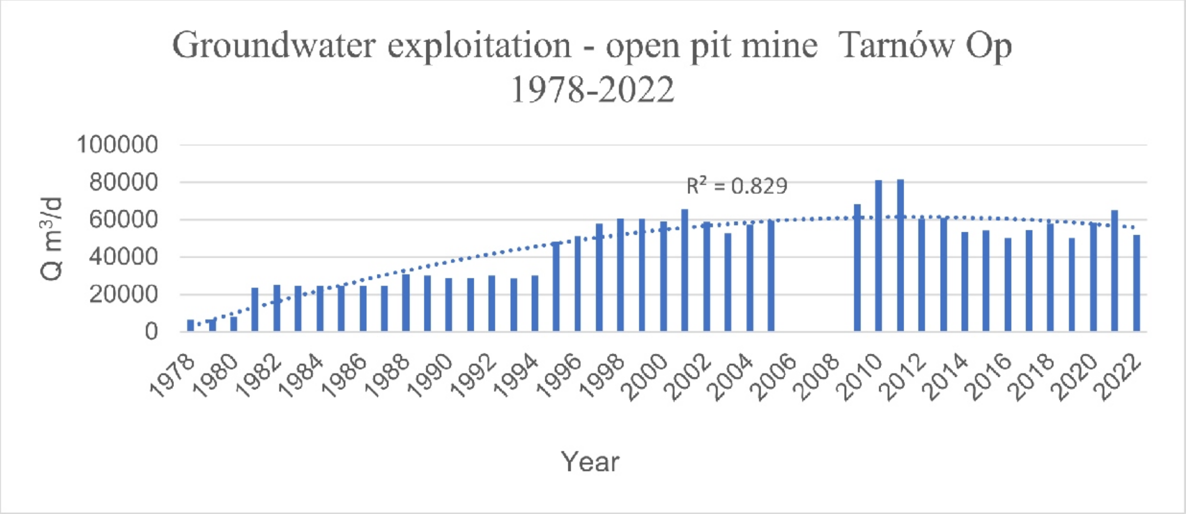

Fig. 24. Groundwater exploitation of the Tarnów Opolski mine 1978–2022

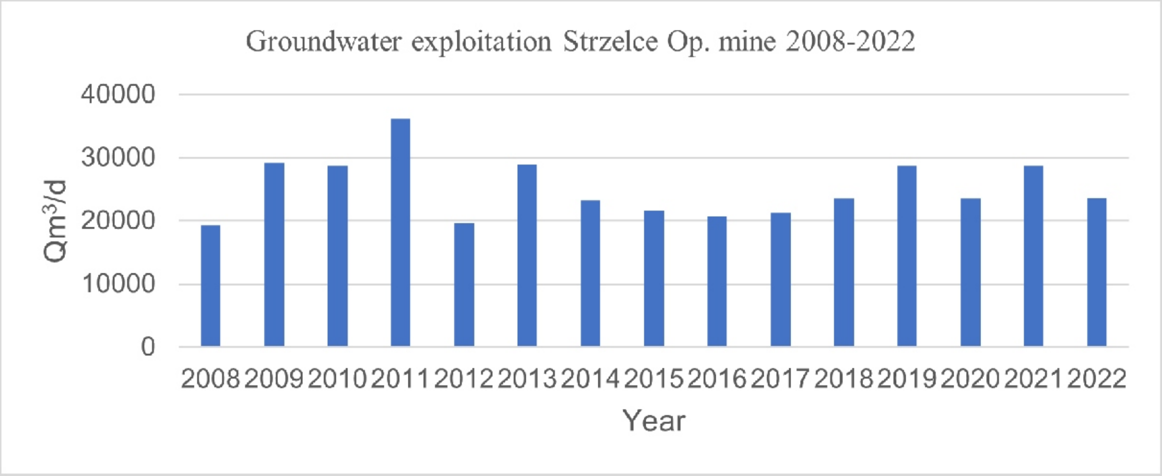

Fig. 25. Groundwater exploitation of the Strzelce Opolskie mine 2008–2022

DISCUSSION

The noticeable increase in air temperature and changes in precipitation in the period researched of the last 70 years in the Opole region is not so clearly shown in the higher-located catchment areas of the springs in the region of Strzelce Opolskie and St. Anna's Mountain. The cyclicity of changes in precipitation distributions and especially the so-called "wet years" have a decisive impact on groundwater resources and the springs' discharge rate. Observations from the beginning of the last century and those of Assmann (1929), found a periodic decrease in the discharge rate of springs in Rożniątów and Sucha, but their disappearance was not noted. This is a typical feature of karst springs, observed long before the period of anthropogenic global warming. The high variability of this type of spring is shown in many papers including Jokiel (1994), Ciężkowski et al. (2009), Kresic and Stefanovic (2010) and Fiorillo et al. (2021). Since the 1980s, with the increase in mine drainage, these springs have shown long periods of no outflow or significant decreases in discharge rates.

Extremely high outflow discharge rates were recorded in the Sucha in the very wet 1981, when the deviation from normal precipitation was +250 mm. The disappearance of the outflow in the years analysed took place in October 1982, which is 13 months after the extremely high precipitation. Two months later, disappearance was recorded in Rożniątów. Disturbing phenomena of outflow disappearance occurred frequently for these springs in following years, 1989 and 1994. Frequent outflow deficiencies were also found over the last twenty years in 2018, 2019 and 2021. Calculation of the average discharge rates of these two springs shows a clear decline, as does the range of discharge. A comparison of average values from the 1980s and the 2020s suggests a significant reduction by up to 5 times in the case of the Sucha spring (see Table 1). Are such large reductions in discharge rate and outflow declines a consequence of climate change? A slight increase of 1.4°C in air temperature does not cause significant changes in groundwater resources, as evaporation is negligible due to the great depth to the water table, e.g., Tarka et al. (2017). It is true that there is a decrease in precipitation of ~5–6% in the last 30 years, but this does not explain such major changes. The search for an explanation of the changes indicates another important component of the area's water balance, i.e., groundwater exploitation. Study of the recession period and value of recession coefficient are illustrated in Table 2.

Forty years ago, a low value of recession coefficient (0.001–0.006) has been typical for the Sucha and Rożniątów springs. By contrast, in recent years this value is one order

Table 2

Comparison of main recession parameters for selected springs

Spring	Recession period	– recession coefficient	V – water volume [m^3]	R – spring's variability
Sucha	1981–1983 104 days	0.0061	2 804,459	265
	2020–2022 65 days	0.056	74,365	126
Rożniątów	1981–1983 154 days	0.00163	983,949	20.4
	2020–2022 75 days	0.063	318,171	116
Odrowąż	1981–1983 84 days	0.00705	1 839,741	2.2
	2020–2022 62 days	0.0085	1 168,941	1.9
Błotnica Strzelecka	1981–1983 86 days	0.008	436,747	2.1
	2020–2022 65 days	0.003	249,543	9.5

higher and as a result a low volume of water is registered, during briefer spring activity. The retardation time reduced from 104–154 days to 64–75 days. No significant changes have been observed in the case of the Odrowąż and Błotnica Strzelecka springs.

There has been an almost 4-fold increase in groundwater pumping by opencast mines since 1994. This significantly affects groundwater resources and the groundwater table in the catchment areas of springs. During periods of low fracture-karst filling, i.e. in dry years, significant water loss contributes to long-term water shortages in the springs of Rożniątów and Sucha.

High rainfall in 2009 (876 mm) and 2010 (955 mm), higher by 170–255 mm than the average, caused significantly higher inflows to the Strzelce Opolskie mine, becoming apparent after one year and noticeable in 2010 and 2011 (28,000–36,000 m^3/d). Similarly, at the Tarnów Opolski mine, inflows were found to be 33% higher in 2010 and 2011 (comp. Figs. 22, 24 and 25). We do not have measurements of the springs' discharge rates from these years, but it can be expected that they were marked by outflows. In turn, in 2011–2019, which were "dry" years, when precipitation was on average 60 mm lower than the average, lower inflows to the mines and a significant lowering of the water table by 4.95–5.5 m were recorded (Kleśta, 2023). Analysing monthly pumping values, a delay of 6–9 months of maximum inflows in relation to anomalously high precipitation was found.

The problem of the impact of mining on surface waters and springs was already signaled in the 1980s (e.g., Raczmański et al., 1984; Zaleska et al., 2006). It was stated, for example, that the high intake of groundwater from four mines (Tarnów Opolski, Strzelce Opolskie, Górażdże and Izbicko) reduced natural flows three-fold in the Sucha River and two-fold in the Chrząstawa River, as well as influenced the disappearance of outflows in Rożniątów and Sucha in 1980–1989 (Nowacki, 1989). In the 1990s, the total groundwater extraction from 15 intakes for supplying urban and rural agglomerations in the municipalities of Tarnów Opolski and Strzelce Opolskie was 8,000–10,000 m^3/d (Zielinski, 1992). However, the dewatering of the two mines in 1987-1992 was almost eight times higher and amounted to 85,000 m^3/d (Podedworna-Piesiak, 1992).

Since 1995, an additional groundwater intake for the city of Opole has been included in the extraction. It is located north of the spring areas in the Grotowice-Utrata water intake for the city of Opole and its pumping rate is of 25,000 m^3/d.

Long-term outflow disappearances in the Sucha and Rożniątów springs were recorded in 2002–2003, as well as in 2018–2019 and 2021–2022. Short-term outflows appeared in Sucha in March 1983, in May 2000 (Duda, 2007) and in April 2021 for two months. Similarly, in Rożniątów the outflow of water lasted briefly from April to July 2021. Recent checks in March and May 2023 documented the appearance of outflows in the Sucha and Rożniątów springs, which can be linked to a significant increase in precipitation of as much as 30% in relation to the annual averages in 2020–2022, especially in the autumn months of 2022. The other two sources in Odrowąż showed variable discharge rates in the range of 115–30 l/s. The sources in Błotnica Strzelecka show much lower discharge rates of 4.7–23.4 l/s compared to those found in the past. The springs researched in Poręba and Gąsiorowice over shorter periods show typical fluctuations in discharge rates (Table 1).

Therefore, the disappearance of outflow in recent years is the result of two factors: climate change and mine dewatering. The aquifer system shows decreased natural outflows in springs in conditions of water scarcity, as indicated by Custodio (2002), among others. Faster groundwater exchange is accompanied by drastic changes in chemical composition. In relation to previous studies (Żurek, 1991; Kryza and Kryza, 2000; Kryza and Staśko, 2000; Rak et al., 2005; Staśko et al., 2022), the fact that there has been a significant increase in total mineralization, sulphate and nitrate in the groundwater of these springs is worrisome. There has been a nearly 4-fold increase in, for example, NO_3 concentrations from values of 10–15 mg/l in 1980–1990 to 40–60 mg/l in recent years (Staśko et al., 2022).

The disposable resources of the Main Groundwater Reservoir No. 333 in both the Roetian and Muschelkalk aquifers amounted to 106,400 m^3/d (Mikołajków and Sadurski, 2017), including 74,791 m^3/d in the municipalities of Tarnow Opolski and Strzelce Opolskie (Łodej, 1989). The total of issued water-legal permits for maximum water pumping for the two discussed mines and intakes for water supply networks significantly exceeds the available resources. In total, it reaches over

210,000 m^3/d. In these conditions, there is a transformation of the natural hydrodynamic system and a departure from sustainable use of the environment. With projected climate change, this will lead to a decline in flows in the river network and exacerbate negative changes in water quality.

Three facts support the statement about the declining trend in the discharge rate of springs and changes in their nature. First, in 1900–1920, the constant character of the outflow in Rożniątów was described, as reported by Assmann (1929). In the 1980s, detailed studies had already shown the periodic nature of the springs in Rożniątów and Sucha, and their short-term disappearances (Staśko, 1992). High water levels in the reservoir rocks caused significant outflows corresponding to the piston flow model of older stored waters, followed by periods without water outflows. The latest research from 2018–2022 documented long periods of no water in the spring and only rare brief outflows of low discharge rates. Over the last hundred years, the permanent spring of Rożniątów and Sucha has turned into a periodic spring.

The variability of the springs' discharge rates was also examined by Jokiel (1994), Chelmicki et al. (2011), Bartnik and Moniewski (2018). The phenomenon of drying up or a significant decrease in the discharge rate of springs has also been noted in the Odra and Warta watershed area, for example, in Zabor (Ordonówki spring), in Złoty Potok (Ostrężnik spring) or in Zdowo (Spring from under the rock). The waters here flow out of the carbonate Jurassic rocks, according to Baścik and Okoń (2022). Similarly, in the areas of the Kraków-Wieluń Upland and Miechowska Upland, a disappearance of 20–28% of the population of 246 springs studied was found in 2011. The springs were recorded in the 1980s and their discharged rates decreased by ~30% (Siwek and Baścik, 2013). By contrast to the Carpathian Catchments in Poland and Slovakia where no trends in the annual baseflow total were determined for most of the catchments examined during 1970–2019 (Siwek and Pociask-Karteczka, 2017) and in the Sudetes (Staśko and Buczyński, 2018), here in the Opole region a decreasing trend in spring discharge is clearly visible. It is counter to discussion on climate change and groundwater recharge as reported on the British mainland (Hughes, 2023) but similar climate and hydrology has been observed in Greece (Koutsoyiannis et al., 2023).

SUMMARY

Low discharge rates or frequent disappearances of outflows in springs draining the Triassic rocks of the Opole region have been observed in recent years. The observed increase in average air temperature and changes in precipitation in 2000–2020 have little effect on the water resources flowing from the springs described. Variable karst springs in Rożniątów and Sucha in the early years of the 20th century became periodic springs in the 1980s. Currently, the springs in Sucha and Rożniątów show much reduced outflows compared to the 1980s. Their outflows appear occasionally with significant increases in precipitation higher by 60–200 mm than monthly averages. There are also alarming declines of discharge rates at springs in Odrowąż, Poręba, Błotnica Strzelecka and Gąsiorowice. Changes in groundwater resources result from precipitation recharge, rising air temperatures and the way water resources are managed. The quadrupling of groundwater extraction in mines significantly affects water resources and the river network. Significant mine dewatering and high groundwater extraction cause negative changes to previously good quality groundwater. Thus, the observed cyclicity of climatic phenomena, the upward trend in air temperature and changes in precipitation, together with the increasing trend in groundwater extraction, has a significant impact on the decline in discharge rate and disappearance of springs. The total number of issued water-legal permits for the Strzelce Opolskie and Tarnów Opolski mines and exploitation for municipal purposes already exceeds the disposable resources for the region. Under conditions of predicted climate change and dry years, this could lead to lower flows in the river network and further deterioration of water quality.

For the preservation of sources, biodiversity, and protection of water resources, it is necessary to include these sources in the groundwater monitoring network of the region.

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