

SEASONAL WATER TEMPERATURE VARIABILITY OF SPRINGS FROM POROUS SEDIMENTS IN GRZYŃYNKA VALLEY, WESTERN POLAND

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ABSTRACT. This paper discusses fluctuations in spring water temperature and its correlation to climate and aquifer characteristics. Data from nine springs in the Gryżynka River catchment (Polish Plain) were taken monthly (November 2005 to October 2010). The springs examined in this study are characterised by significant thermal inertia in contrast to air temperature, that is expressed in small temperature amplitudes that range from 1.3°C to 2.3°C. The average temperature of the springs is about 9°C. The research proved that observed groundwater temperature variations on the surface resulted mainly from atmospheric conditions, especially air temperature. The highest water temperatures (up to 10°C) were observed during late summer and early autumn, and the lowest temperature (7.7°C) was observed at the end of the winter period. The range of spring water temperature variability may reflect amount of water contribution from local water recharge in the spring vicinity.

KEY WORDS: springs, spring water temperature, groundwater monitoring, Poland

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1. Introduction

Analysing the groundwater that emerges in springs was found to be an easy and fast tool research method (Aldwell, Burdon 1986), then the springs should be considered important elements of an environmental monitoring network (Bender *et al.* 2001). Measuring the temperature of spring water aids the assessment of heat flow from the

surface to the groundwater (Bundschuh 1993, Manga 1998, Musgrove *et al.* 2010) and of the influence of geothermal heat on spring water temperature (Manga, Kirchner 2004, Leaver, Unsworth 2007). Such measurement also assists in the determination of residence time in underground and the direction of its circulation (James *et al.* 2000, Becker *et al.* 2004, Baena *et al.* 2009). Bundschuh (1995) suggested applying water temperature

measurements as one of the methods to assess potential groundwater contamination, a concept that is also suggested in Malard and Chapuis (1995) and Wampler and Sisson (2010). Groundwater temperature measurements have been used to analyse the effects of urbanisation and climate change on the underground environment (Taniguchi, Uemura 2005, Taylor, Stefan 2009). Other potential applications of spring water temperature measurements include assessment of use of groundwater resources for drinking, industrial purposes and balneology (Manga 2001).

Springs located in areas that consist of sedimentary porous rocks (sand, gravel, etc.) are much less studied than the springs that originate in fissured rocks or karst formations. However, the field studies that were conducted on the topic in recent decades proved that they occur more frequently than had previously been assumed and that they serve as an important hydrographic element where they exist (e.g. Bender *et al.* 2001, Szczucińska, Marciniak 2008, Chełmicki 2011, Szczucińska in press). For instance, in areas that were shaped by ice sheets during the Last Glacial Maximum and are covered with thick glacial and glacialfluvial deposits, the share of the spring water discharge in the river reaches 30% (Szczucińska 2009). However, the thermal properties of the water that emerges from them have been little studied. This paper presents the seasonal and inter-annual temperature variability of spring water that flows from porous media (sediments) to discuss the natural factors that affect these variations and to assess the utility of spring water temperature monitoring in areas with porous sedimentary aquifers.

2. Study area

This paper studies springs that are located in the Gryżynka River catchment, which is part of the Lubuska Plateau in the western Polish Lowlands (Fig. 1). The catchment area is approximately 77.5 km², and approximately 76% of the area is covered by forests, with the remainder covered by crop fields (16%) or village buildings and water bodies (8%). Gryżynka river source is located at a height of 75 m a.s.l. The river joins the Odra River after 17 km at a height of 42 m a.s.l. The

main feature of the basin is the 30-m-deep tunnel valley of the Gryżynka river, which drains the catchment area. The valley cuts through sandur deposits (mainly sand and gravel) and reaches the groundwater level, thus resulting in numerous groundwater outflows. Altogether, 354 groundwater outflows have been documented in the basin, and these have been ordered into 70 groups. The spring density, calculated as number of groups, is 0.95 per square kilometre (Szczucińska 2009). The basic characteristics of the studied springs are presented in Table 1.

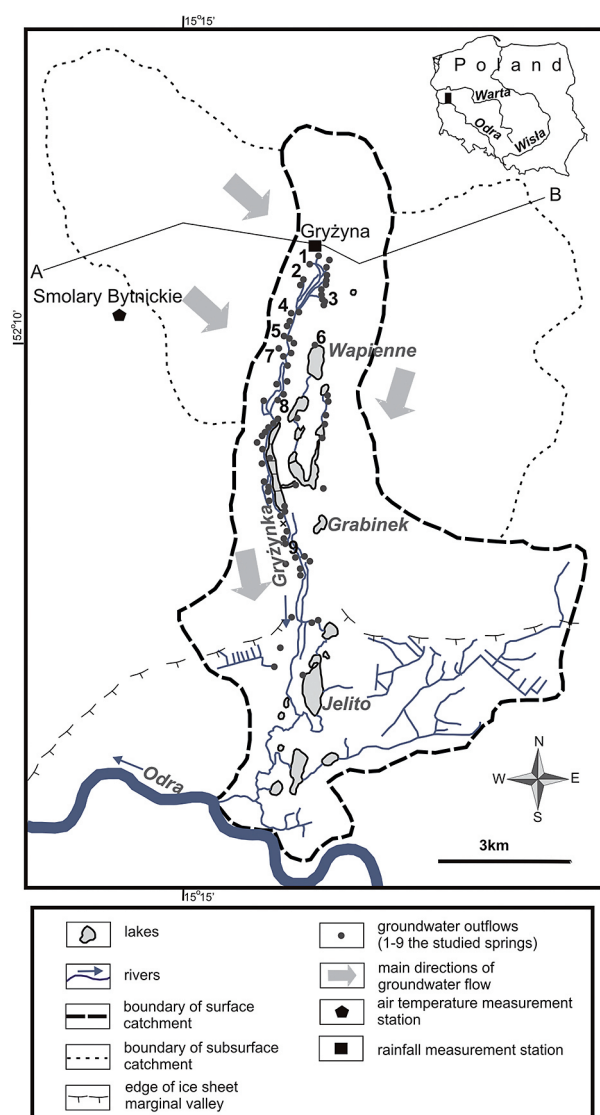


Fig. 1. Locations of the springs in the Gryżynka-Grabin Tunnel Valley. The monitored springs are marked with numbers 1 to 9. The inset shows the location of the study area in Poland. Transect Line A–B marks the location of the hydro-geological cross-section that is presented in Fig. 2

Table 1. Basic characteristics of the springs. Average discharge and specific electrical conductivity (SpC) after Szczucińska (2009)

Spring	Average discharge dm^3s^{-1}	SpC μScm^{-1}	Form of water outflow	Morphological position	Land-use of area in the neighborhood of spring
1	43	422	descending-ascending	at the slope base	village, forest
2	0.6	524	descending	at the slope base	village, forest
3	0.9	474	descending	at the slope base	village, forest
4	22	371	descending-ascending	at the slope base	fields, forest
5	6.5	485	descending	at the slope base	fields, forest
6	3.3	427	descending	at the slope base	tourist resort, forest
7	0.5	348	descending	at the slope base	forest
8	2	340	descending	at the slope base	forest
9	0.6	263	descending	at the slope base	forest

The groundwater that emerges from these springs flows through Pleistocene sediments, the thickness of which varies from 30 m in the southern part of the catchment to 150 m in the western part (Fig. 2). These sediments are composed of intercalated sands, gravel, glacial tills, silts and glacial clays. The variable arrangement of the permeable and semi-permeable beds within the Quaternary sediments results in an aquifer with complex hydro-geological properties, with hydraulic conductivity values in range of $2 \cdot 10^{-6}$ to $9 \cdot 10^{-5} [\text{m s}^{-1}]$ (Szczucińska 2009).

The study area is located in a transitional zone between the oceanic and continental temperate climate zone. The average annual temperature is

8.2°C (Woś 1999), and the average annual precipitation is about 630 mm (Graf 2006).

3. Methods

The temperature of the spring water was measured once a month between November 2005 and October 2010 in nine springs using a calibrated electronic thermometer ETI 2001, with 0.1°C accuracy. Measurements were taken at the point of water outflow from the ground.

The average monthly air temperatures were obtained from the automatic meteorological station in Smolary Bytnickie, which is located 8 km

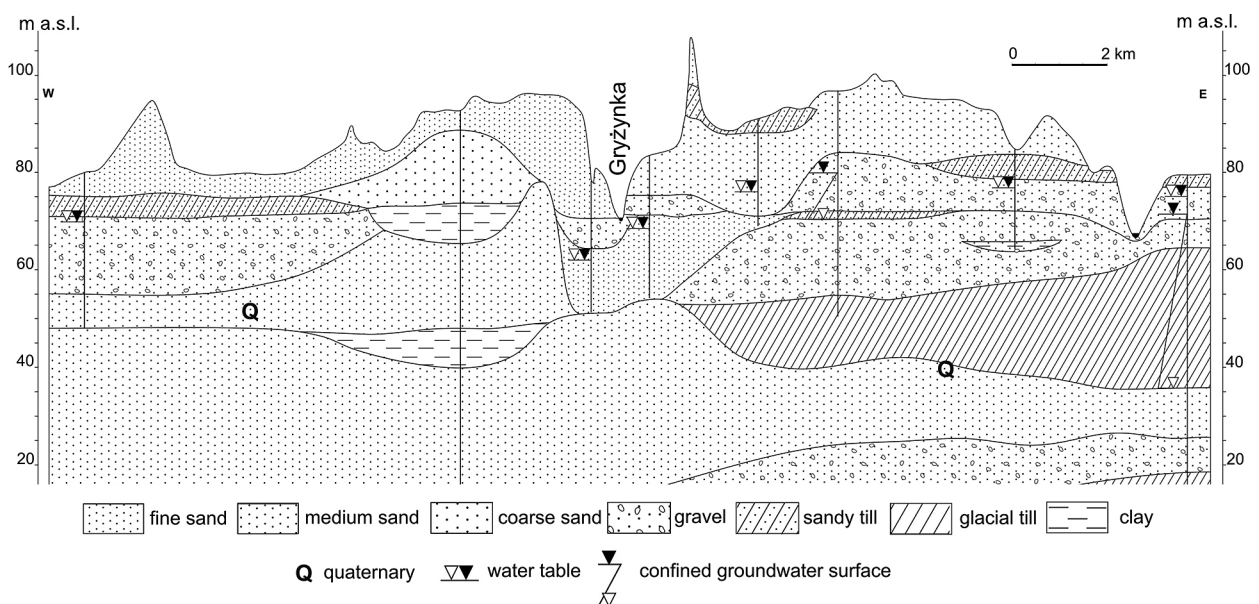


Fig. 2. Hydro-geological cross-section along Line A-B (Fig. 1) through the Gryżyna-Grabina Tunnel Valley

from the border of the Gryżynka River’s surface catchment (Fig. 1). The station is at 77 m a.s.l. in extra-urban area.

Monthly precipitation data was acquired from the precipitation meteorological station of the Institute of Meteorology and Water Management (IMGW), located at an altitude 80m a.s.l., in Gryżyna village (Fig. 1). The precipitation was measured by Hellmann Precipitation Recorder, that was set 1m above ground surface.

4. Results

The water temperatures that were measured in the nine springs are presented in Fig. 3A. The average water temperature of particular springs

varied between 8.8°C and 9.2°C (Table 2). The amplitude of the average temperature the seven springs did not exceed 2°C (Table 2). The lowest temperature, 7.7°C, was observed in Springs 2 and 3 in March and January 2006, respectively, and the highest temperature (10.0°C) was measured in Spring 2 in September 2009. The lowest average water temperature in the nine springs was observed between January and March 2006 and was equal to 8.2°C. The highest average spring water temperatures varied from 9.4°C to 9.8°C and were observed from August to October in 2008, 2009 and 2010. In 2006, the highest average water temperatures were measured in November, and in 2007, the highest temperatures occurred in June and July. Their values were 9.4°C, 9.4°C and 9.5°C, respectively.

The average air temperature during the study period (Fig. 3B), measured at the meteorological station was 7.4°C and it was 0.8°C lower than the average temperature in the last three decades. In 2006, 2009 and 2010, the lowest average temperatures were recorded in the coldest month (January) at -8.6, -5.6 and -8.8°C, respectively. Winters in 2007 and 2008 were considerably warmer. The lowest monthly average air temperatures in 2007 were observed in February (-0.1°C) and December (-0.3°C), and in 2008 in January (-0.5°C). The average temperature of the summer months (July–September) was 17.7°C and 16.1°C in 2006 and 2009, respectively, but the summer season of 2007 exhibited a colder average air temperature at 14.8°C.

The total annual precipitation (Fig. 3C) during the study period varied from 478 mm in 2006 to 723 mm in 2008, and the average total annual precipitation for Poland is 600 mm (Woś 1999). In years 2006 to 2009, the precipitation was equal during the cold and warm halves of the year. In the year

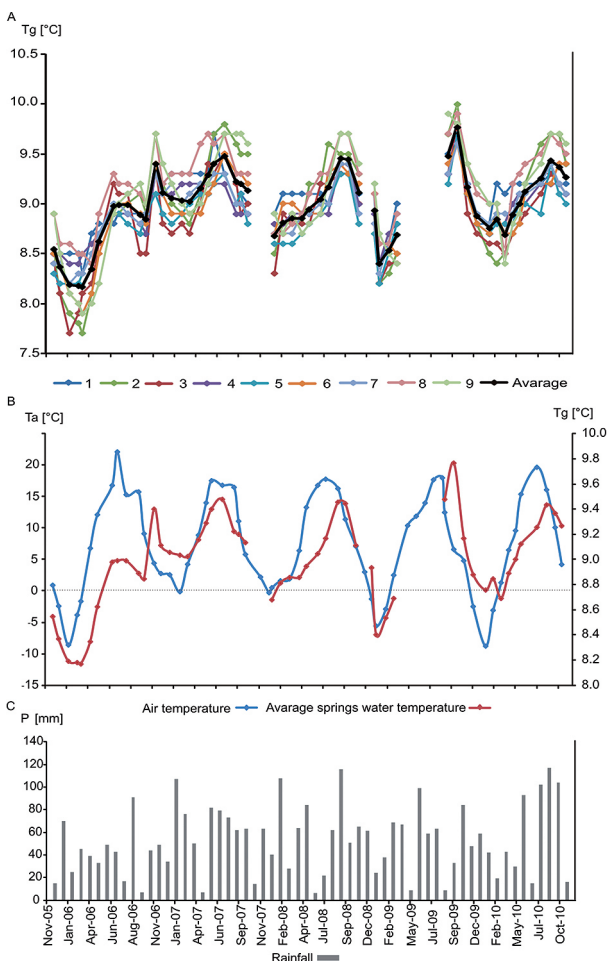


Fig. 3. A) Monthly average water temperature of the nine monitored springs (numbered 1–9 in Fig. 1) and the average temperature of all spring waters between November 2005 and October 2010; B) the monthly average water temperature of the nine analysed springs compared to the monthly average air temperature

Table 2. Summary of the maximum, minimum and mean water temperature, as well as the maximum observed amplitude for the monitored springs in period November 2005 and October 2010

Spring No.	1	2	3	4	5	6	7	8	9
Tmax	9.8	10	9.8	9.7	9.7	9.6	9.6	9.9	9.9
Tmin	8.3	7.7	7.7	8.4	8.2	7.9	8.2	8.4	7.9
Amplitude	1.5	2.3	2.1	1.3	1.5	1.7	1.4	1.5	2.0
Mean	9.1	9.0	8.8	8.9	8.8	8.9	8.9	9.2	9.1

2010 nearly twice as much rainfall was during the warm half of the year as during the cold half.

5. Discussion

5.1. Characteristics of the springs based on their water temperature

Water temperature is one of the basic parameters of groundwater classification. According to commonly used spring water classification system, the long-term average air temperature is compared with the average spring water temperature in a given region (Hackett 1998). Under this approach, the spring waters of the Gryżynka basin are classified as "normal waters" because their average temperature is approximately 9°C and is similar to the long-term average air temperature of the region (8.2°C) (Woś 1999).

The small amplitudes in the spring water temperatures, in the range from 1.3°C to 2.3°C, may demonstrate that the springs are charged with waters, drained from regional voluminous groundwater aquifers (Fig. 1). It is confirmed by available preliminary results of water isotopes measurements suggesting that the residence time of water in the aquifers is from 30 (Spring 1 and 5) to about 100 (Spring 9) years (Szczenińska 2009) and moderate hydraulic conductivity values in the aquifer sediments. Manga (1999) analysed the temperatures of spring waters from fractured aquifer rocks in Oregon and observed small (0.1–0.2°C) monthly amplitudes in spring water temperatures. He also concluded that the springs drained waters from large aquifers and remained in the subsurface for at least a decade.

5.2. The relationship between spring water temperature and air temperature

The main factor that affected the water temperature of the springs was the type of groundwater that drained from the aquifer. The low variation of water temperatures (amplitudes in range of 1.3°C to 2.3°C) suggest that the majority of the spring water may come from waters that are confined to the deeper part of the aquifer, which is located beneath the zone of season-

al temperature changes. However, as Figure 3B shows, the minor fluctuations in the spring water temperature generally follow the pattern of average monthly air temperature changes, with a correlation coefficient of 0.62 at the 0.001 significance level (*p*). Thus, the variations in the spring water temperature reflect a secondary contribution from the subsurface waters, which are subject to seasonal air temperature changes. The spring water temperature may be also affected by direct contact with the atmosphere or by mixing with the precipitation waters that infiltrate toward the springs from nearby areas. This explanation is in agreement with seasonal changes in water hydrochemistry of the studied springs (Szczenińska *et al.* 2010).

Cross-correlation coefficients were calculated to determine whether the atmospheric air temperature was reflected in the short term (e.g., due to direct warming or cooling due to contact with air or water), or with some delay (e.g., due to the transit time in the subsurface area). The analyses considered correlations of spring water temperature with air temperature in the same month (*r*0), in the previous month (one step; *r*1), two months prior (two steps; *r*2) and three months prior (three steps; *r*3). Table 3 depicts the detailed results of the cross-correlation. The significant heat capacity of the vadose zone causes the water temperature to change with a 1–2 month delay to the change in the average air temperature. For sev-

Table 3. Correlations and cross-correlations of spring water temperatures and air temperatures (*r*0: of the same month as the water temperature, *r*1 – of the month before, *r*2 – of the two months before, *r*3 – of the three months before). *r*0 – correlation coefficient *r*1–*r*3 – cross-correlation coefficients with a step from 1 to 3. The highest values of cross-correlation coefficients are underlined

Spring No.	<i>r</i> 0	<i>r</i> 1	<i>r</i> 2	<i>r</i> 3
1	0.44	<u>0.45</u>	0.41	
2	0.69	<u>0.82</u>	0.78	
3	0.68	<u>0.75</u>	0.65	
4	0.49	<u>0.55</u>	0.52	
5	0.61	<u>0.68</u>	0.6	
6	0.55	0.72	<u>0.77</u>	0.64
7	0.59	<u>0.64</u>	0.57	
8	0.61	<u>0.73</u>	0.69	
9	0.46	0.73	<u>0.85</u>	0.76

en of the springs, the strongest correlation was found between water temperature and the average air temperature of the previous month (from 0.64 to 0.82, $p = 0.05$). For two other springs, the strongest correlation was with the air temperature two months prior (0.77 and 0.85, $p = 0.05$). The weakest correlations and cross-correlations between the spring water temperature and the air temperature were observed in Springs 1 and 4. This may be related to the location of the water outflows; in both cases, the springs are situated at the foot of slopes that are approximately 10 m in height, so even water that recharges directly above the springs requires a relatively longer period of time to reach them.

5.3. The influence of precipitation on spring water temperature

In the case of springs that drain sedimentary porous media, the reaction to precipitation has rarely been recorded (Moniewski 2004), and in the present study, as seen in Figure 3C, the amount of precipitation shows no clear correlation with the spring water temperatures. The correlation coefficient between monthly precipitation and spring water temperature is 0.3 at the 0.05 significance level, but the type of precipitation is of great importance. For example, during brief rainfall events, most of the water flows down the slopes directly into the Gryżynka River. During longer periods of rainfall, however, the temperature and the otherwise stable discharge of spring water may change. For example, in October 2009, the average spring water temperature increased due to the high temperatures of the summer months and likely due to the greater amount of precipitation during that month. The influence of precipitation is likely because the rainfall occurred at a time when average daily temperatures were relatively high. For example, October 7, the average temperature reached 16.8°C, although the monthly average temperature for October was 6.6°C. However, in order to identify spring water reaction to the precipitation (e.g. change in discharge, water temperature, electrical conductivity), more frequent monitoring needed to be carried out, especially in the period after rainfall.

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6. Conclusions

Temperature data taken from selected springs that drain sedimentary porous aquifers in the temperate climatic zone demonstrated that:

- Groundwater that emerged from the springs revealed very small temperature amplitudes due to their significant thermal inertia in contrast to air temperature. The average temperature measured in the springs was approximately 9°C and was comparable to the air temperature of the region.
- The observed seasonal spring water temperature changes were only 1°C to 2°C and followed variations in air temperature. The changes resulted probably from the admixture of shallow subsurface groundwater, direct warming and/or cooling at the spring and long-term rainfall periods.
- This research showed that groundwater temperature provides valuable information about not only the subsurface environment but also about the water sources. The higher amplitudes of spring water temperatures may reflect bigger contribution from local recharge in the vicinity of springs. This observation may be useful in defining the protection zones for springs used for water intake.
- The monthly measurements of spring water temperature show general variation. However, the future studies should include daily or hourly measurements which may be useful for identification of the rate of reaction of spring water to the local recharge.

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