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HYDROLOGIC AND CHEMICAL WATER REGIME IN THE CATCHMENTS OF BYSTRA AND SUCHA WODA, IN TATRA NATIONAL PARK

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ABSTRACT

The chemistry of surface water and groundwater is subject to constant changes, which result primarily from meteorologic factors (for instance, amounts and intensity of atmospheric precipitation), hydrologic factors (for instance, degree of hydration of the mountain massif and changes in river flows), and geologic-lithologic factors (type of bedrock). The aim of the present study was to examine the hydrologic and chemical regime of surface and groundwater in the Bystra and Sucha Woda mountain catchments.

Between December 2013 and December 2016, a total of 77 series of measurements were collected at a rate of twice per month (n = 611 water samples) at 8 gauging sites, which represented both surface waters (streams, ponds) and groundwater (karst springs). The studied area features two very distinct forms of geology. The southern part is a crystalline region, and the northern part is formed of sedimentary rocks. During field studies, the following were measured: water levels and discharge of streams, conductivity, pH, and temperature of water. At the same time, water samples were collected for laboratory analysis, which included total dissolved solids (TDS) and concentration of Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, SO_4^{2-}, Cl^-, NH_4^+, PO_4^{3-}, NO_3^-, Li^+, Br^- i F^- ions.

Geologic structure produces the greatest impact on water chemistry in the Bystra and Sucha Woda catchments. Waters representing the crystalline region were characterized by significantly lower TDS, conductivity, and ion concentrations than waters from the crystalline-sedimentary (karst) region. The average TDS for the crystalline region was 14.3 mg · dm^{-3}, while for the crystalline-sedimentary region, 81.2 mg · dm^{-3}. Waters in the crystalline region were characterized by a demonstrably lower pH (average 6.5 pH) than waters in the karst region (average 7.7 pH).

The low TDS, conductivity and concentration of main ions were also accompanied by increased discharge during the summer and autumn. In all the examined waters, there was also a marked decrease in the value of these parameters during the spring thaw. In the feeding of streams and karst springs during this time, low-mineral-content meltwaters had their significant share. In spring, there was also the greatest variation in the chemistry of the studied waters. This variability was clearly lower in the Bystre Dolne karst spring than in the Goryczkowe karst string. This was most likely related to a different rate of meltwater inflow in the two karst springs. In the tested waters, the highest TDS, conductivity and concentration of main ions occurred at winter low discharge, which resulted from the predominance of groundwater influx in river discharge. In all the studied waters, a clear decrease in the NO_3^- concentration was observed during the summer and autumn months. Most probably, this was associated with increased NO^- uptake by plants during the growing season. In streams draining the crystalline part of the Bystra catchment there was clearly a lower nitrate concentration than in the Bystra stream draining the crystalline-sedimentary (karst) part.

The chemistry of Bystra stream water draining the crystalline-sedimentary (karst) part of the catchment was closely dependent on the chemistry of groundwater from the Goryczkowe and Bystre Dolne karst springs.

Keywords: Tatras, water chemistry, nutrients, high mountains

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INTRODUCTION

The chemistry of river waters is primarily determined by the geologic structure of the catchment (Johnson et al. 1969; Rice, Bricker 1995; Cameron 1996, Burns et al. 1998). Hydro-meteorologic conditions such as the amount and spatial distribution of atmospheric precipitation during the year as well as the seasonal dynamics of river discharge also play an important role (Feller, Kimmins 1979; Hem 1989; Bhangu, Whitfield 1997; Żelazny, Siwek 2012). The important role of substrate rocks (bedrock) in shaping the chemistry of waters found in the Tatra Mountains was shown by Oleksynowa and Komornicki (1996) and Małecka (1989). This also results in a zonation of the chemistry of waters in the Tatra Mountains (Żelazny 2012).

Małecka (1989) and Barczyk (2008) also noted the important role of the water circulation rate and the size of recharge zones, in particular in the case of karst springs, which usually also drain areas outside their parent catchment. Investigations of seasonal changes in ion concentration in Tatra karst springs included the Chochołowskie and Lodowe Źródło karst springs (Wolanin, Żelazny 2010) and Olczyskie karst spring (Wójcik 2012). Due to the occurrence of complex karst systems and numerous karst springs, the Bystra stream catchment area has been the subject of numerous studies in the fields of hydrogeology (Barczyk 2008; Wit, Ziemońska 1960; Małecka 1997) as well as hydrochemistry (Oleksynowa, Komornicki 1990; Żelazny 2012).

The circulation of ions in catchments is a topic that is discussed in the research literature. Detailed studies on the circulation of calcium, nitrogen, sulfur and phosphorus were conducted in the Hubbard Brook catchment in the White Mountains in the United States by Likens and Bormann (1995), and in several forested catchments in the Catskill Mountains in the United States by Murdoch and Stoddard (1992).

The aforementioned studies indicate that NO_3 concentrations in stream water are closely related to the stage of the growing season in a given catchment (Johnson et al. 1969; Betton et al. 1991; Reynolds et al. 1992; Lepistö 1995; Arheimer et al. 1996; Bhangu, Whitfield 1997; Miller, Hirst 1998; Holloway, Dahl- gren 2001; Sullivan, Drever 2001; Clark et al. 2004). According to Lovett et al. (2005), the change in the chloride concentration in stream water during the year is also related to the growing season and to summer absorption of chloride by the root system of trees. Some researchers argue, like Lynch and Corbett (1989), that the changes in the concentration of nitrogen and sulfur compounds in stream water are associated with variable atmospheric deposition of these compounds during the year. Likens et al. (1967) and Siwek (2012) also indicated high seasonal variation of potassium, whose concentration was lower in the course of the summer growing season than in winter.

The aim of the study was to learn more about the hydrologic and chemical regime of surface water and groundwater in the Bystra and Sucha Woda catchments.

STUDY AREA

The research study was carried out in the Bystra catchment, located on the boundary between the Western Tatras and High Tatras (Kondracki 2002), and in the Sucha Woda catchment. The highest point in the Bystra catchment is Kondracka Kopa (2,004 m above sea level), and in the Sucha Woda catchment, Świnica is the highest peak (2,301 m above sea level). The average inclination of slopes in the Bystra catchment is 26.8º (Żelazny 2012). The catchment of Bystra is characterized by complex geologic structure. The southern part of the area is formed of crystalline rocks, mainly granite and granodiorite rocks, and also metamorphic rocks. The northern part is formed of sedimentary rocks affected by strong karst processes. These are mainly limestones and dolomites as well as conglomerates, quartz sandstone, shale and marl. The bottom of the Bystra valley and of Sucha Woda valley is lined with rock waste sediments from the Holocene and Pleistocene (Piotrowska et al. 2015). The southern part of the Bystra catchment is cut by a system of valleys, which experienced strong transformation in the Pleistocene due to glacier impact (Klimaszewski, 1988). The central and northern parts are part of a trough valley, which in the lower course had been extended by proglacial waters. The studied area is characterized by the presence of vegetation and climatic zones (Hess 1996). The average temperature drop is 0.5ºC per every 100 m. The lowest parts are located in the lower montane zone (up to 1,200 m above sea level), where spruce is the most dominant tree species; the central part of the Bystra catchment is located in the upper montane zone (up to 1,550 m above sea level) dominated by spruce forest; the upper parts are located in the subalpine zone with a predominance of mountain pine (up to 1,800 m above sea level); and alpine grasslands occur in the alpine zone (over 1,800 m above sea level) (Mirkowa-Piękoś 1996). The annual amount of rainfall increases with elevation, and in the highest parts, it can reach 2,000 mm (Hess 1996). Snowfall yields a high share of the area's precipitation. Different types of soils were observed in the studied catchments (Skiba et al. 2015). In the southern part of the catch- ment, these are mainly raw-humus rankers, podzolic soils, and raw debris soils. There are podzols occur- ring on moraine sediments. On sedimentary rocks, there are different types of rendzinas (proper redzina, raw debris soils, raw-humus rankers, brown soils, brown pararendzinas). In the central and northern part of the catchment, at the bottom of the valley and in the lower parts of slopes, there are also dystrophic brown soils as well as eutrophic brown soils and brown alluvial soils.

METHODS

The research was carried out from December 2013 to December 2016 and it included the sampling of surface waters (streams, ponds) and groundwaters (karst springs) in the Bystra catchment and in the Sucha Woda catchment. Water samples were collected in disposable polyethylene bottles at 8 gauging sites (see: Fig. 1, Table 1).

A total of 77 measurement series were taken at a rate of twice per month (n = 611 water samples). At two gauging sites, the temperature was also measured (every day at 7:00 a.m.), as was discharge at the time of water sampling (at sites 7 and 2). The determination of the concentrations of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{2-}, Cl^{-} and NO_3^{-} ions in water was performed by means of ion chromatography using a DIONEX ICS-2000 chromatograph. The total of all the determined ions, for the purpose of further analysis, is defined as the total dissolved solids (TDS). Statistical analyses were performed using Statistica 13.1 software. A Piper diagram made using Grapher 13 software was used for the analyses. In order to analyze the hydrologic and chemical regime, the year was divided into four parts corresponding to the main seasons: spring, summer, autumn and winter.

RESULTS AND DISCUSSION

Waters from crystalline areas were characterized by a much lower TDS, lower conductivity, and lower concentration of the majority of main ions than waters from crystalline-sedimentary (karst) areas. For example, the waters of Goryczkowy Potok (stream),

Table 1. Characteristics of gauging sites

Gauge	Name	Longitude	Latitude	Height above sea level [m a. s. l.]	Part of catchment
1	Bystra stream – Kuźnice	19.98216	49.27704	955	Crystalline sedimentary
2	Bystra stream downstream of karst springs	19.97205	49.25875	1,150	Crystalline sedimentary
3	Bystre Dolne karst spring	19.96850	49.25527	1,170	Crystalline sedimentary
4	Bystra stream upstream of karst springs	19.96839	49.25466	1,170	Crystalline sedimentary
5	Goryczkowe karst spring	19.97246	49.25435	1,201	Crystalline sedimentary
6	Goryczkowy Potok stream	19.96834	49.24541	1,325	Crystalline
7	Niżnia Goryczkowa Rówień stream	19.96818	49.24497	1,327	Crystalline
8	Zielony Staw (pond)	19.99770	49.22930	1,675	Crystalline

Source: own study based on data

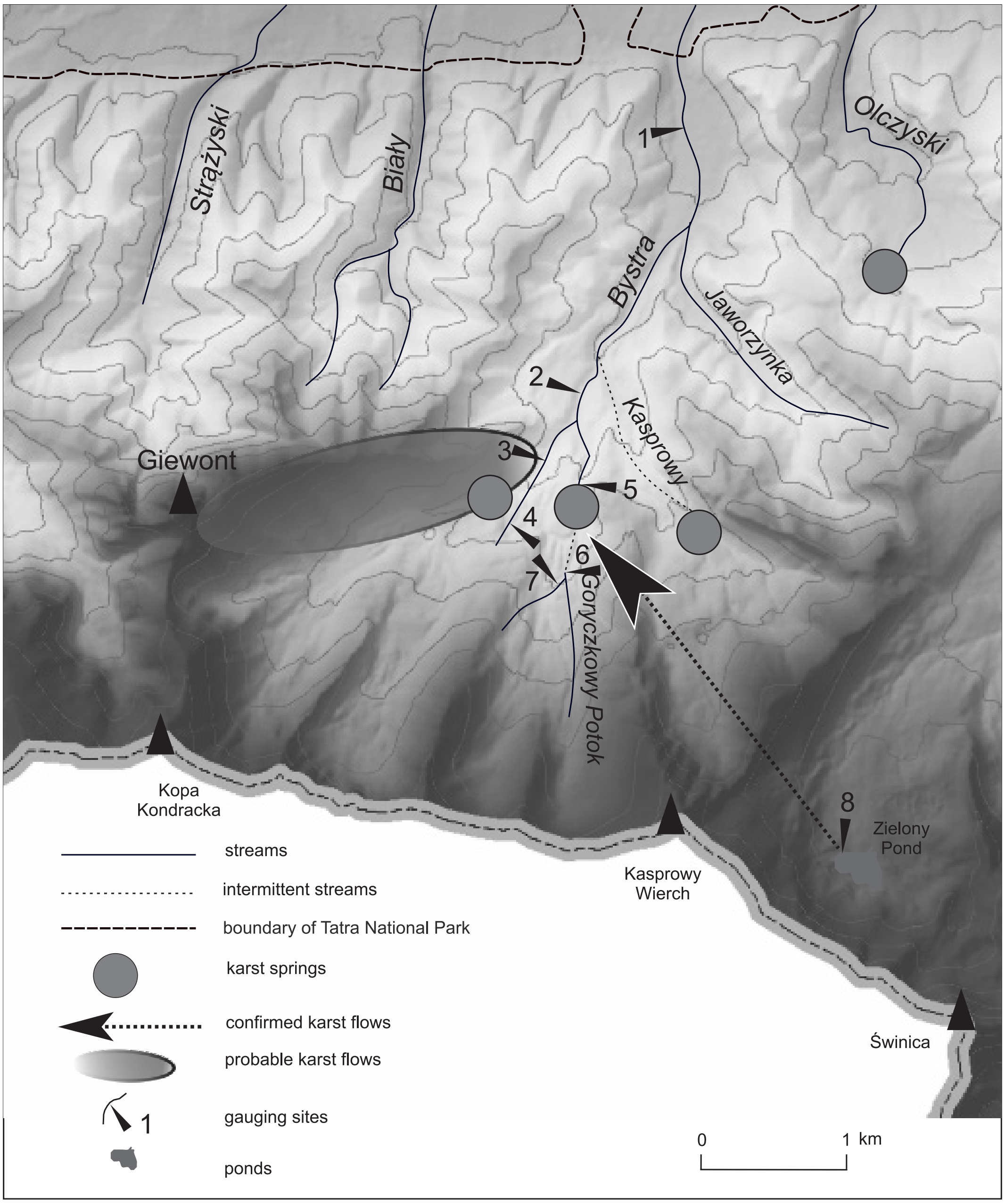

Fig. 1. Study area: Bystra and Sucha Woda catchments. Location of gauging sites

Source: own study

draining the crystalline part of the catchment, were characterized by average TDS of 12.9 mg · dm^{-3} (see: Table 2), whereas the waters of Bystra stream below the inflow of the Goryczkowe and Bystre Dolne karst springs had a six times higher average TDS, namely 83.4 mg · dm^{-3}. According to Oleksynowa and Komornicki (1996) as well as Żelazny (2012), such a large difference is related to the geologic structure of this area: streams and springs draining the crystalline part have little possibility of leaching poorly soluble granitoid and metamorphic rocks, unlike the streams and springs that drain sedimentary areas, mainly formed of karst limestone, dolomite, and shale. Waters in the crystalline region were characterized by a clearly lower average pH (6.5) than water in the karst region (average: 7.7).

Furthermore, waters flowing from the crystalline part of the Bystra catchment were characterized by a lower proportion of Ca^{2+} and HCO_3^- in their chemical composition than waters in streams and karst springs of the crystalline-sedimentary part (see: Fig. 2). This is associated with a very high content of calcite ($CaCO_3$) and dolomite ($CaMg[CO_3]_2$) in sedimentary deposits, and their negligible content in crystalline formations (Gaweł 1959). The streams that drain the crystalline part were characterized by a higher proportion of Na^+ and K^+ in their water chemistry, which results from the relatively high content of sodium compounds (plagioclase, for example, albite $Na(AlSi_3O_8)$) and potassium (orthoclase $K[AlSi_3O_8]$, muscovite $KAl_2[AlSi_3O_{10}(OH)_2]$, and biotite $K[AlSi_3O_{10}(OH)_2]$ in crystalline rocks (Gaweł 1959). The waters of Zielony Staw (pond) are characterized by low TDS (see: Table 2), similar to waters from the southern part of the Bystra stream. They differ in terms of higher calcium content and lower content of magnesium, sodium and potassium – among cations (see: Fig. 2).

The chemistry of the studied waters was subject to changes throughout the year. These changes clearly referred to changes in discharge. In the Goryczkowy Potok stream representing the crystalline catchment average discharge was 9.8 $dm^3 \cdot s^{-1}$, and the coefficient of variation was 111.8%, while in the Bystra stream downstream of karst springs, draining the crystalline-sedimentary catchment, average discharge was 832 $dm^3 \cdot s^{-1}$, and the coefficient of variation was almost two times lower – it was 54.2% (Sajdak 2017). This results from a much smaller catchment area, and most likely much faster water circulation in crystalline catchment due to the low retention capacity of parent material (Wit, Ziemońska 1960). In streams draining the crystalline catchments the lowest discharge is observed in the winter months, when most water is stored in the snow cover, whereas high discharge is observed in summer and autumn when there is heavy rainfall (see: Fig. 3). In the spring, higher discharge appears, which is caused by thaws. The lowest water temperatures are recorded in winter, and the highest in summer (see: Fig. 3). Similar seasonal changes in water temperature are observed in the Bystra stream downstream of karst springs (crystalline-sedimentary catchment); however, due to the fact that discharge in the stream is determined by karst springs, water temperature fluctuations are much smaller than in the crystalline part.

Table 2. Average TDS and ion concentrations at gauging sites

Gauging site		1	2	3	4	5	6	7	8
TDS		106.90	83.38	93.97	42.69	78.79	12.94	14.91	14.89
Ca^{2+}		18.79	15.43	17.03	7.97	14.84	1.89	2.30	3.09
Mg^{2+}		4.50	3.11	3.65	1.24	2.89	0.45	0.53	0.21
Na^+		0.89	0.89	0.88	1.08	0.90	1.00	1.04	0.47
K^+	$mg \cdot dm^{-3}$	0.41	0.36	0.37	0.33	0.36	0.21	0.24	0.21
HCO^-		73.31	54.79	64.80	26.43	49.87	5.71	6.68	8.12
SO^{2-}		6.73	6.70	5.07	3.87	7.75	2.49	2.74	1.55
Cl^-		0.43	0.32	0.32	0.40	0.32	0.22	0.23	0.21
NO^-		1.76	1.72	1.77	1.31	1.76	0.91	1.08	0.96

Source: own study based on data

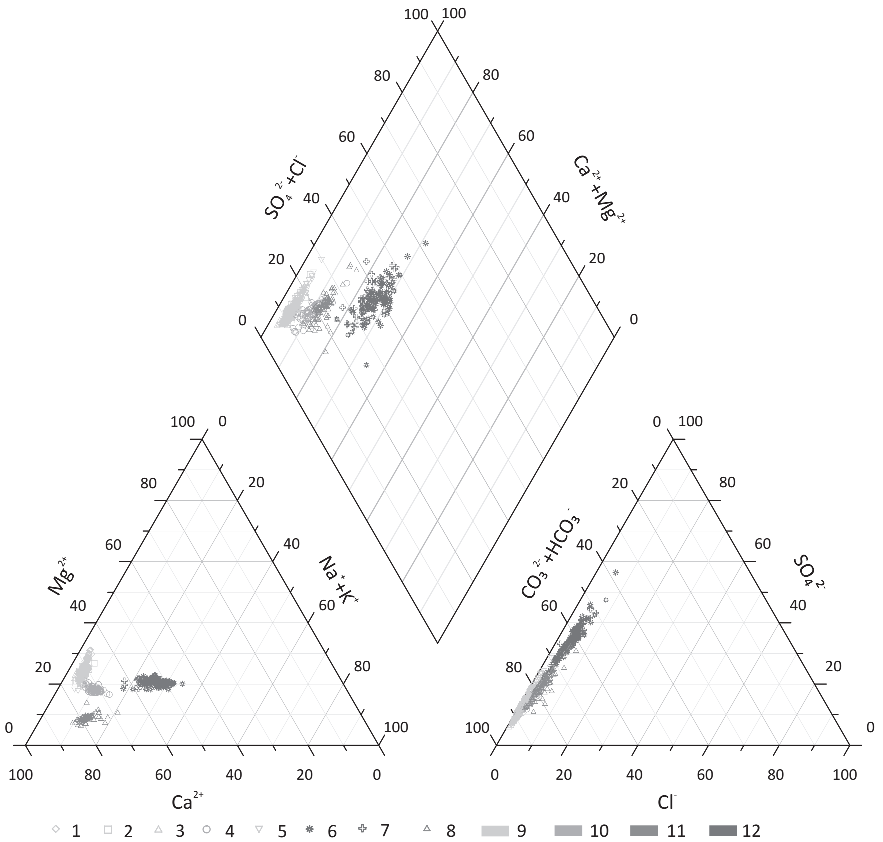

Fig. 2. Percentage of main ions in all studied waters. 1. Bystra stream – Kuźnice, 2. Bystra stream downstream of karst springs, 3. Bystre Dolne karst spring, 4. Bystra stream upstream of karst springs, 5. Goryczkowe karst spring, 6. Goryczkowy Potok stream, 7. Niżnia Goryczkowa Rówień stream, 8. Zielony Staw (pond), 9. Karst part of the catchment, 10. Crystalline-sedimentary part of the catchment, 11. Crystalline part with a predominance of granitoid rocks, 12. Crystalline part with a predominance of metamorphic rocks.

Source: own study based on data

Streams draining both the crystalline and crystalline-sedimentary parts of the Bystra catchment exhibited significantly lower TDS, conductivity, and main ion concentrations in summer and autumn than in spring and winter. Lower values of the analyzed parameters accompanied increased discharge during summer and autumn. Influx of rainwater characterized by low value of TDS to streams caused a dilution of the stream water. In the winter and early spring, the studied streams were supplied almost exclusively by groundwater, as water from precipitation was now being stored in the snow cover. In the late spring, the snow cover melted and released the water trapped in it. The low TDS of water from snow melting reached streams and diluted their waters. Therefore, the greatest differences in TDS, conductivity, and concentration of most major ions occurred in the spring. This is evidenced by the higher quartile distances of the tested parameters in the spring than in other seasons (see: Fig. 4 and Fig. 5). The dilution of stream water at elevated water stages is a common occurrence, and as such it is often described in the literature (for instance, Cameron 1996; Bhangu, Whitfield 1997; Muscutt, Whithers 1996; Drużkowski 1998; Pekarova et al. 1999; Żelazny, Siwek 2011). In the majority of the studied waters, there was a higher share of SO_4 and Cl in their chemistry during spring and winter than during summer and

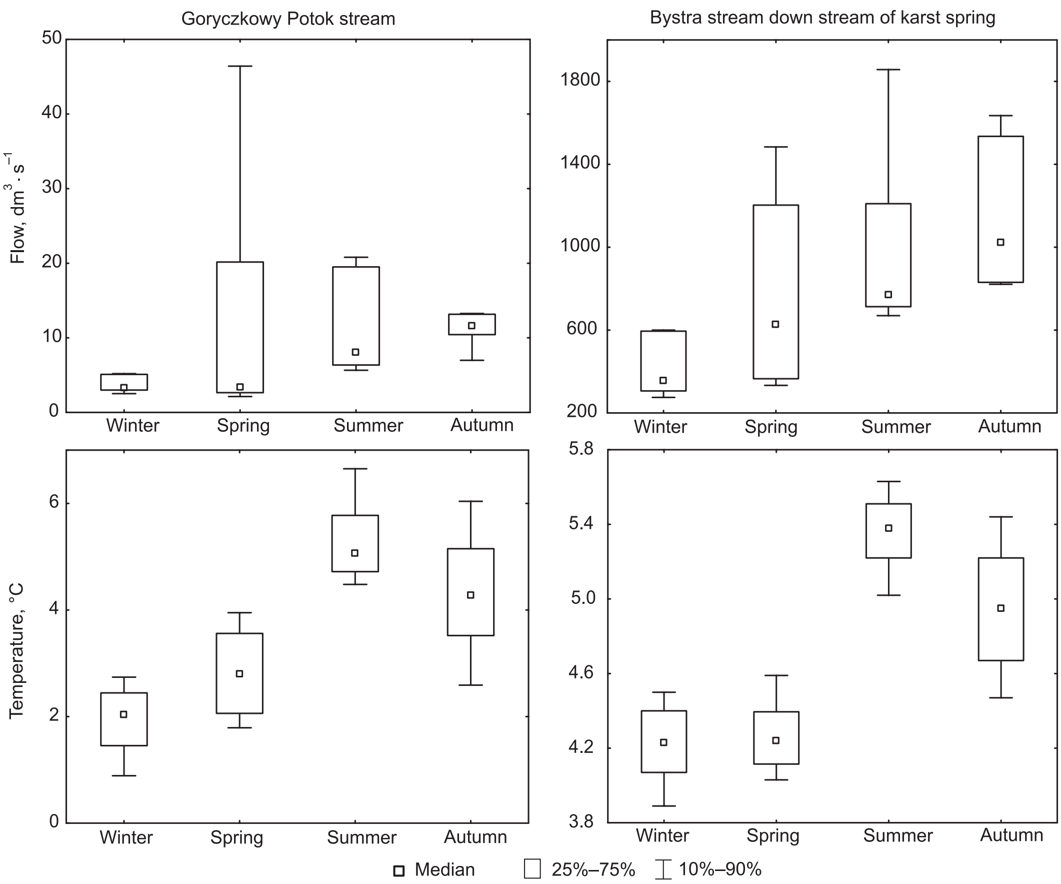

Fig. 3. Seasonal variability of discharge and water temperature in the stream draining the crystalline part of the catchment (Goryczkowy Potok stream) and crystalline-sedimentary part of the studied catchment (Bystra stream downstream of karst springs)

Source: own study based on data

autumn. The explanation of this pattern requires further research (see: Fig. 6).

In the Goryczkowe karst spring, the lowest TDS, conductivity, and concentration of the majority of main ions occurred usually in the summer, while in the Bystre Dolne karst spring in the autumn. Distinctly higher values of these parameters occurred in the spring and winter. In the Goryczkowe karst spring, similarly to the streams in both the crystalline and crystalline-sedimentary parts of the Bystra catchment, variability in water chemistry in the spring was noticeably higher than in other seasons. In the Bystre Dolne karst spring, such a pattern was not observed. The variability in the water chemistry in the Bystre Dolne karst spring was clearly smaller than that in the Goryczkowe karst spring, which is confirmed by lower coefficients of variation, generally not exceeding 15% (see: Table 3). Perhaps at very high discharge, surplus water from Goryczkowy Potok stream had entered the Goryczkowe karst spring – the surplus water that had not been absorbed in the ponor zone above the karst spring. The fact that this type of occurrence is very probable is evidenced by the existence of a dry streambed upstream of the Goryczkowe karst spring. This is also indicated by the high dilution of the waters of Goryczkowe karst spring, especially during the spring thaw, for which the influx of the low TDS waters of Goryczkowy Potok stream would be responsible. The dilution of the water in the Goryczkowe karst spring is much greater than of the water in Bystre Dolne karst

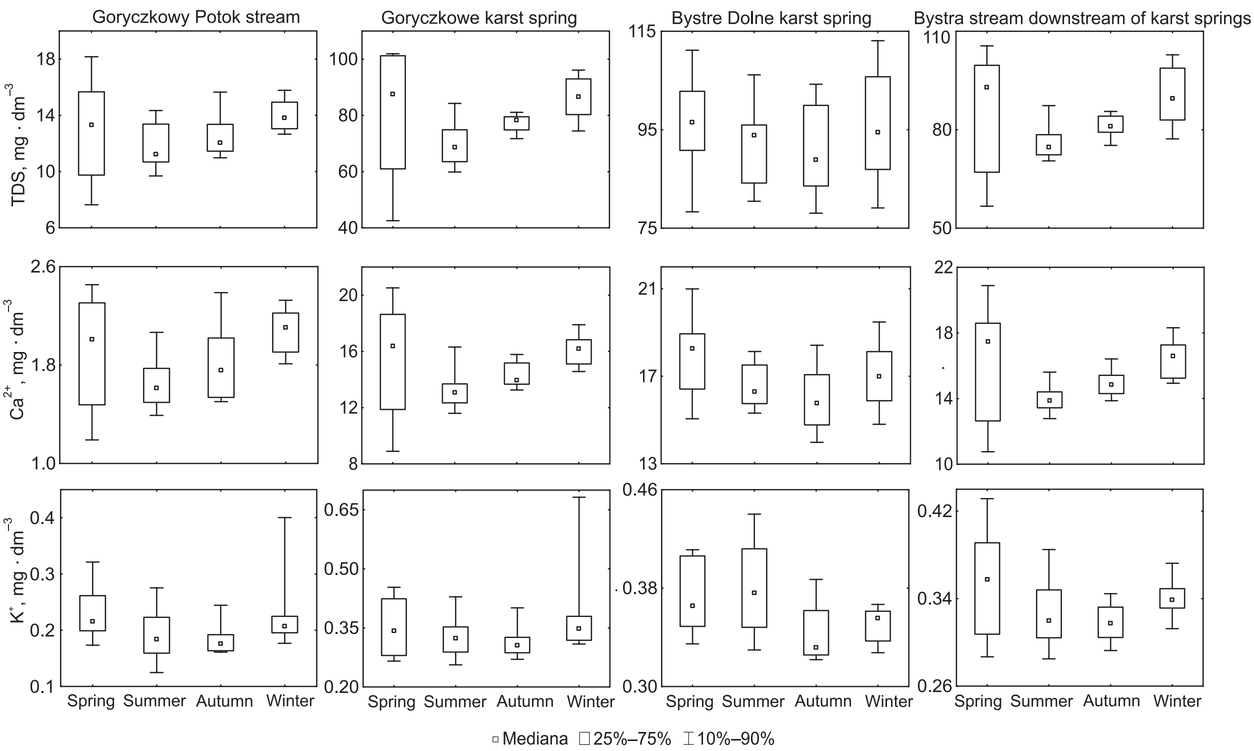

Fig. 4. Seasonal changes in TDS and concentration of Ca^{2+} and K^+ in stream water and spring water

Source: own study based on data

spring (see: Fig. 3). Goryczkowe karst spring is fed by the water from the Zielony Staw (pond) and the Myślenickie Turnie massif (Barczyk 2008), whereas the Bystre Dolne karst spring is probably fed by the water of the Giewont massif (Małecka 1997) and from the valleys of the Małe Szerokie, Kondracka and Sucha Kondracka (Gromadzka et al. 2015).

In all the studied waters, a clear decrease in NO^- concentration was observed during the summer and autumn months. Most probably, this was associated with increased NO_3^- uptake by plants during the growing season. In streams draining the crystalline part of the Bystra catchment, there was clearly a lower nitrate concentration than in the Bystra stream downstream of karst springs (crystalline-sedimentary catchment. For instance, in Goryczkowy Potok stream (crystalline catchment), the average concentration of NO_3^- was 0.9 mg · dm^{-3}, whereas in the Bystra stream downstream of the influx of water from karst springs, it was twice as large: 1.8 mg · dm^{-3} (see: Table 3). The difference was most pronounced during summer and autumn. A high variability of NO_3^- concentrations in the streams draining the crystalline part of the catchment was noticeable in the spring. Such high variability of NO_3^- concentrations was not observed in the streams and springs of the crystalline-sedimentary catchments (see: Fig. 5). The probable cause of such rapid changes in the NO_3^- concentration in the streams draining the crystalline part of the catchment was the leaching of NO_3^- from soils via infiltrating meltwater, and its supply via throughflow. NO_3^- concentrations in waters from karst springs were characterized by high stability throughout the year, as evidenced by the low coefficients of variation of NO_3^- (see: Table 3). The water chemistry of Bystra stream downstream of karst springs draining the crystalline-sedimentary part of the catchment was strictly dependent on the chemistry of groundwater from Goryczkowe and Bystre Dolne karst springs. According to Wit and Ziemońska (1960), these karst springs largely determine the discharge of Bystra stream.

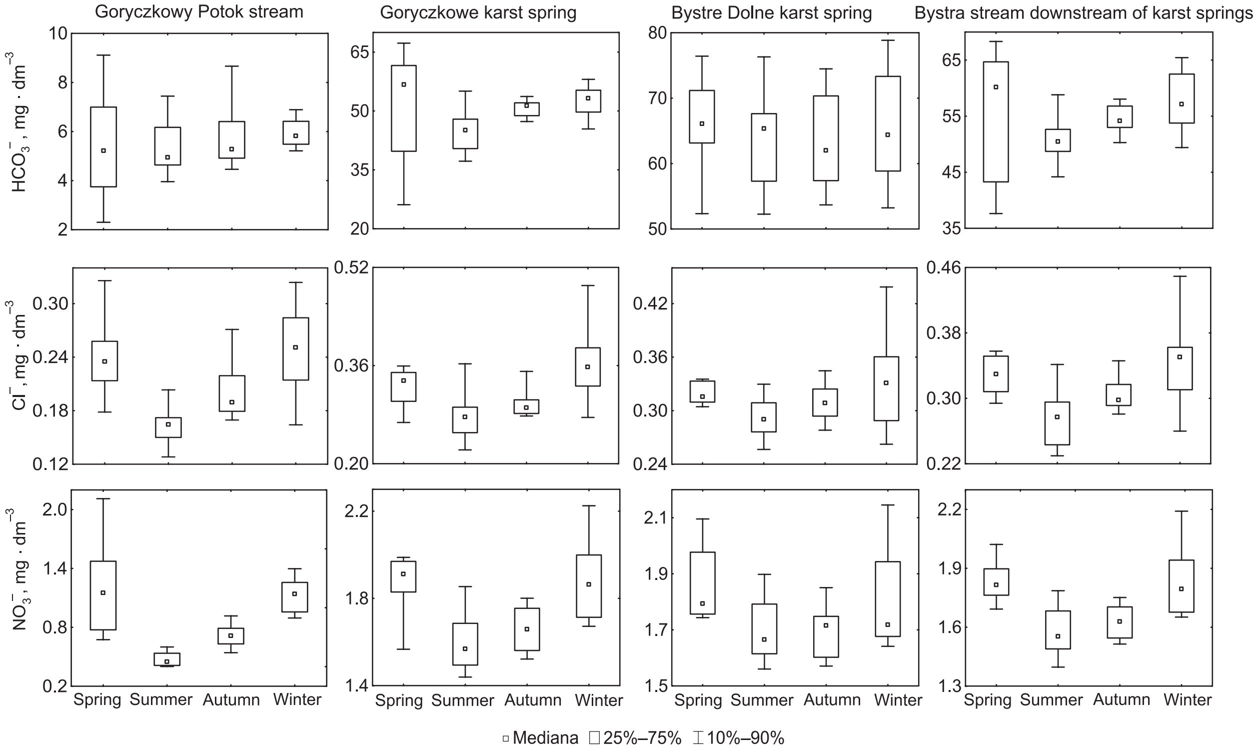

Fig. 5 . Seasonal changes in concentration of HCO_3^-, Cl^- and NO_3^- in stream water and spring water

Source: own study based on data

Table 3. Coefficient of variation of TDS and ion concentrations for each gauging site

Feature		1	2	3	4	5	6	7	8
TDS		19.6	14.3	12.3	24.1	17.7	18.9	16.7	15.5
Ca^{2+}		17.3	14.5	12.5	23.7	17.1	20.9	18.6	13.9
Mg^{2+}		27.6	20.4	12.3	26.2	24.5	21.1	17.5	21.4
Na^{+}		9.9	7.4	8.4	8.0	11.8	12.8	13.0	15.1
K^{+}	[%]	32.2	52.6	24.7	18.6	36.4	34.2	33.1	42.0
HCO^{-}		20.1	13.5	13.6	29.7	16.7	28.3	24.4	22.6
SO^{2-}		26.7	32.4	14.2	10.4	38.3	13.5	11.4	13.2
Cl^{-}		39.8	16.0	18.8	26.0	19.6	27.7	20.5	39.8
NO^{-}		14.3	11.1	9.8	43.1	12.4	47.3	28.3	41.2

Source: own study based on data

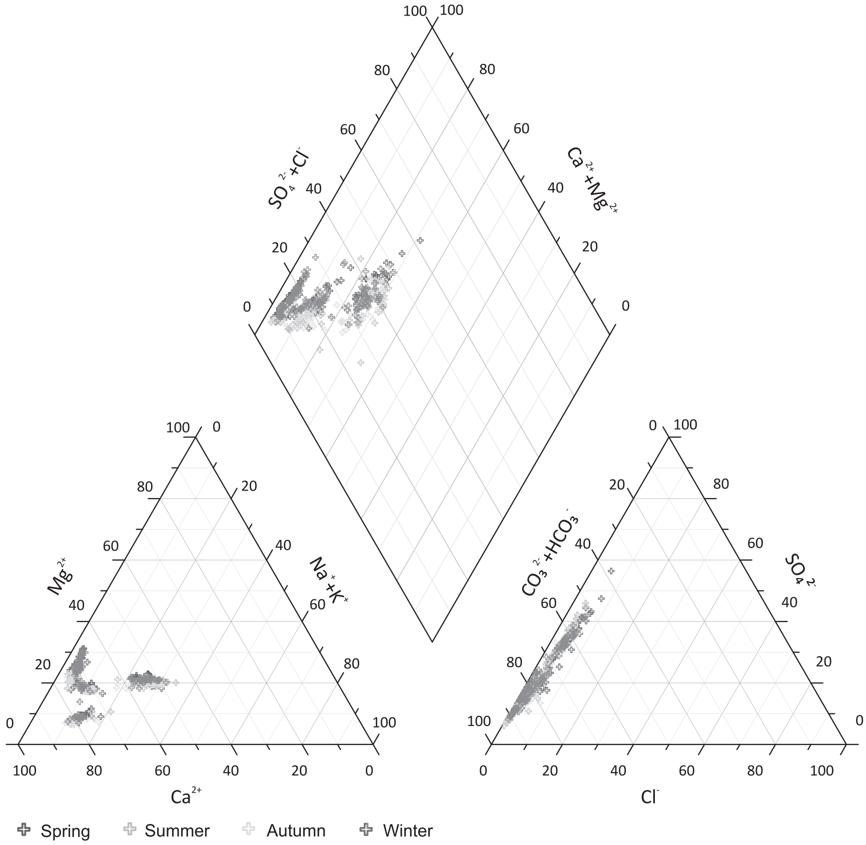

Fig. 6. Percentage of main ions in all studied waters according to season

Source: Own study based on data

CONCLUSIONS

The studied crystalline areas, due to faster circulation of water, are characterized by a greater variability of discharge over the year than crystalline-sedimentary areas.

The crystalline part of the Bystra catchment is characterized by very low TDS of water due to circulation in sparingly soluble rocks. The waters of the crystalline-sedimentary part, the chemistry of which is shaped by karst springs, are characterized by a several times higher TDS.

Lower TDS, conductivity and ion concentrations are observed in summer and autumn than in the winter and spring in all the studied waters. It is due to the dilution of groundwater with rainwater at higher discharge in summer and autumn.

Spring is characterized by larger changes in water chemistry than all other seasons. In early spring, streams are mainly recharged by groundwater with a relatively high TDS, while in late spring they are mainly recharged by low TDS water from melting snow.

In the stream water draining the crystalline part of the Bystra catchment, there was a distinctly lower nitrate concentration than in the Bystra stream water draining the crystalline-sedimentary part. During the summer and autumn months, all waters that had been tested exhibited a clear decrease in the NO_3^- concentration, which was most probably associated with increased NO_3^- uptake by plants during the growing season.

The water chemistry of Bystra stream draining the crystalline-sedimentary part of the catchment was determined by the groundwater chemistry of the Goryczkowy and Bystre Dolne karst spring.

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REŻIM HYDROLOGICZNO-CHEMICZNY WÓD W ZLEWNIACH BYSTREJ I SUCHEJ WODY (TATRZAŃSKI PARK NARODOWY)

ABSTRAKT

Skład chemiczny wód powierzchniowych i podziemnych podlega ciągłym zmianom, których przyczyną są przede wszystkim czynniki meteorologiczne (np. wielkość i natężenie opadów atmosferycznych), czynniki hydrologiczne (np. stopień nawodnienia masywu górskiego i zmiany przepływu rzecznego) oraz geologiczno-litologiczne (rodzaj skał budujących podłoże). Celem badań było poznanie reżimu hydrologiczno-chemicznego wód powierzchniowych i podziemnych w zlewniach potoku Bystra i Suchej Wody.

Od grudnia 2013 r. do grudnia 2016 r. zebrano 77 serii pomiarowych w rytmie 2 razy w miesiącu (n = 611 prób wody) z 8 stanowisk, które reprezentowały zarówno wody powierzchniowe (cieki, staw) jak i podziemne (wywierzyska). Badany obszar cechuje się wyraźną dwudzielnością geologiczną. Południowa część to region

krystaliczny, a północna część jest zbudowana ze skał osadowych. W terenie mierzono stany wody cieków, natężenia przepływu oraz cechy fizykochemiczne wód, takie jak przewodność elektryczna właściwa, pH oraz temperaturę wody. Równocześnie pobierano próbki wód do analiz laboratoryjnych, które obejmowały mineralizację ogólną oraz stężenia jonów Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, SO_4^{2-}, Cl^-, NH_4^+, PO_4^{3-}, NO_3^-, Li^+, Br^- i F^-.

Największy wpływ na skład chemiczny wód w zlewni potoku Bystra i Suchej Wody miała budowa geologiczna. Wody reprezentujące region krystaliczny cechowały się znacznie niższą mineralizacją ogólną, przewodnością elektryczną właściwą i stężeniem jonów niż wody w regionie krystaliczno-osadowym (krasowym). Średnia wartość mineralizacji ogólnej w regionie krystalicznym wynosiła 14,3 mg · dm^{-3} a w regionie krystaliczno-osadowym – 81,2 mg · dm^{-3}. Wody w regionie krystalicznym cechowały się wyraźnie niższym pH (średnia: 6,5 pH) niż wody w regionie krasowym (średnia: 7,7 pH).

Niskie wartości mineralizacji, przewodności elektrycznej właściwej oraz stężenia głównych jonów towarzyszyły podwyższonym przepływom w czasie lata i jesieni. We wszystkich badanych wodach zaznaczał się również wyraźny spadek wartości tych parametrów w okresie wiosennych roztopów. W zasilaniu potoków i źródeł (wywierzysk) w tym czasie znaczny udział miały słabo zmineralizowane wody roztopowe. Wiosną występowała też największa zmienność składu chemicznego badanych wód. Zmienność ta była wyraźnie mniejsza w wywierzysku Bystrej Dolnym niż w wywierzysku Goryczkowym, co najprawdopodobniej było związane z różnym tempem dopływu wód roztopowych do obu wywierzysk. We wszystkich badanych wodach najwyższe wartości mineralizacji ogólnej, przewodności elektrycznej właściwej oraz stężenia głównych jonów występowały w czasie zimowej niżówki, co wynikało z przewagi zasilania podziemnego w odpływie rzecznym. We wszystkich badanych wodach obserwowano wyraźny spadek stężenia NO_3^- w czasie miesięcy letnich i jesiennych. Najprawdopodobniej związane było to ze zwiększonym poborem NO_3^- przez rośliny w sezonie wegetacyjnym. W wodach potoków odwadniających krystaliczną część zlewni potoku Bystra występowało wyraźnie niższe stężenie azotanów niż w wodach potoku Bystra odwadniającego część krystaliczno-osadową. Skład chemiczny wód potoku Bystra, odwadniającego krystaliczno-osadową część zlewni, był ściśle uzależniony od składu chemicznego wód podziemnych z wywierzysk Goryczkowego i Bystrej Dolnego.

Słowa klucze: Tatry, hydrochemia, azotany, góry wysokie