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HUMAN IMPACT ON PHYSICAL AND CHEMICAL PROPERTIES OF SPRINGS FROM CRACOW-CZĘSTOCHOWA UPLAND (SOUTHERN POLAND)

ABSTRACT: The water chemistry, granulometric composition and organic matter content of the sediments in 25 springs of the Cracow-Częstochowa Uplands (Southern Poland) were studied. The springs (range of discharge: 0.01–1440 l s^{-1}) were cool with almost constant temperature (7–10°C), and the content of calcium, SO_4 and oxygen saturation were also fairly constant throughout the year. Springs from the northern region differed in pH and discharge from springs from the southern region of the Uplands. Average nutrient contents were high (4.1 mg NH_4 dm^{-3}, 7.5 mg NO_3 dm^{-3}, 1.04 mg PO_4 dm^{-3}) in those springs which are under the influence of human impact (i.e. local source pollution from farms and agriculture management). The sediments in the springs of the southern part of the Upland were mostly silt, containing 4% of organic matter (dry weight), while the sand fraction, with a low (0.9%) organic matter content dominated in substrates of the northern Upland springs.

KEY WORDS: karstic springs, water chemistry, sediments, Cracow-Częstochowa Upland

1. INTRODUCTION

Springs are valuable landscape features and provide unique habitats for aquatic fauna and flora. They offer many advantages for various ecological studies since they are small ecosystems with relatively stable physical and chemical parameters.

Many investigators have exploited springs as good laboratories and a relatively simple system for ecological and evolutionary studies. Springs have been studied in the past and there is a number of early, classic works on springs ecology and their flora and fauna communities published by Thienemann (1924), Ischreyt (1927), Odum (1957). The peak in the interest of the ecology of springs was between the time of the 1950's and 1960's with renewal of research interest in the late 1990s. The "spring renaissance" has produced a number of new conceptual approaches to understanding subterranean waters and crenal as an important freshwater habitat types and the branch of aquatic ecology dealing with its study is presently widely acknowledged (Gibert *et al.* 1994, Botosaneanu 1998).

In Europe, as well as in North America, many ecological studies were conducted on springs from different geographical regions e.g. in England (Smith and Wood 2002), in Finland (Särkkä *et al.* 1997), and in Sweden (Hoffstein and Malmqvist 2000). Polish studies of springs have also long and good tradition (Demel 1922, Pax and Maschke

1936). The best studied are “Niebieskie Źródła” springs in Central Poland, where hydrochemical, biological and ecological studies were performed twice in about 30 years (e.g. Tończyk *et al.* 2000). Hydrochemistry as well as single elements of biocenosis were studied in springs from various regions of Poland (Biesiadka and Czachorowski 1999).

The Cracow-Częstochowa Upland located in Southern Poland (50°10′–50°46′N, 19°17′–19°54′E) is known as an area rich in springs. They drain Jurassic and Cretaceous limestone and marl deposits from one of the largest karstic aquifers in Poland which is partly exploited for drinking water. The land is largely forested, but includes meadows and areas used for agriculture. Recreation is also important in this area and the human impact has a negative influence on many of the springs, some of which have been recently destroyed by the construction of water intakes, roads, buildings and other structures. This trend towards degradation and decreasing quality of the spring water has highlighted the need for research and protection of springs located within the Cracow-Częstochowa Upland. Dynowska (1983) has already suggested that many of these springs should be protected for their specific landscape value and ecological attributes. Indeed some of them are now considered as special nature protection units called inanimate nature monuments and have been protected by law since 2002 (Tyc 2004).

The water and sediment qualities are important determinants of the ecological state of a spring and may influence the diversity of its fauna (van der Kamp 1995). The chemical composition of the Cracow-Częstochowa Upland spring waters have been studied by many scientists, such as Oleksynowa (1966), Różkowski (1996), Tyc (1997), Chełmicki (2001), Motyka *et al.* (2002), Siwek and Chełmicki (2004). In 2003, within the research project of State Committee for Scientific Research “Multivariate analysis of fauna distribution in karstic springs of Cracow-Częstochowa Upland”, chemical and biological studies were conducted in 25 of the springs in this region. The subject of this paper is to describe the abiotic environment of the spring ecosystems: the physical and chemical parameters of the water as well as the granulometric composition and organic matter content of their sediments.

2. STUDY AREA

Fifteen of the springs (1–15) studied are located in the southern part of the Upland, mostly situated in Ojców National Park, while the other 10 springs (16–25) are located in the northern part of the Upland (Fig.1). The area under investigation consists mainly of Upper Jurassic limestone which has an important influence on the groundwater conditions. Within the southern part of the Upland loess and calcareous soils predominate, whereas in the northern part permeable, sandy and loamy soils predominate. The water circulates within the fissured, karstic limestone of the Upland and its flow is not uniform, which is due not only to the different sizes of the fissures, but also to different lithology of the limestone (Dynowska 1983, Chełmicki 2001).

The majority of the springs studied are rheo-limnocrene, that is, the basin is very small and the water flows out rather slowly. In 2003 the level of the underground water was very low, which resulted in drying out of many springs, especially in the northern part of the Upland (A. Tyc, pers. comm.) but the springs sampled in this study are characterized by permanent outflow, except for No 4 (Fig. 1) which dried out completely in the middle of the study. Spring No 23 (Fig. 1), which has a small catchment, and underground water is circulating in a shallow horizon stopped flowing out in the autumn of 2003. A small pool remained from which samples were taken for water analyses.

The studied springs are situated in various drainage basins, and they represent different hydrogeological types and discharge values (Table 1). They have also various storage time in the spring basin. The southern Upland region has the highest density of springs which usually have a very low discharge, about 0.001–15 l s^{-1} characteristic for springs with smaller catchments, descending type of feeding layer and water level only a few dozen meters deep. Springs in the northern region have much higher discharges (20–1440 l s^{-1}), which characterize hill-side springs, ascending type of their feeding layer and water level

Table 1. Location (see Fig. 1) and characteristics of studied springs. The discharge data (annual average or only one data) according to Dynowska (1983) and Chełmicki (2001).

	Spring number	Drainage basin of the stream (river)	Type of spring*	Discharge (l s^{-1})
Southern Part	1	Sąspówka (Prądnik)	scarp-foot, karst, encased	0.6
	2	Sąspówka (Prądnik	scarp-foot, descending, karst, encased	1.0–4.4
	3	Sąspówka (Prądnik	terrace, descending, limnorheocrene	5.0–5.6
	4	Sąspówka (Prądnik	valley, limnocrene	0.01
	5	Sąspówka (Prądnik	scarp-food, descending, karst, rheocrene	8.0–9.8
	6	Sąspówka (Prądnik	terrace, descending, rheocrene	0.8–1.0
	7	Sąspówka (Prądnik	scarp-foot, descending, karst, limnorheocrene	*ca.* 1.0
	8	Sąspówka (Prądnik	terrace, descending, rheocrene	*ca.* 3.0
	9	Prądnik (Wisła)	nearchannel, scarp-foot, descending, fissure, encased	5.0-6.0
	10	Prądnik (Wisła)	nearchannel, descending, partly encased	0.5
	11	Prądnik (Wisła)	nearchannel, descending, encased	0.4–2.0
	12	Prądnik (Wisła)	scarp-foot, descending, karst, encased	12.5–15.0
	13	Prądnik (Wisła)	scarp-foot, descending, karst, rheocrene	4.0–11.0
	14	Prądnik (Wisła)	terrace, descending, encased	0.5–0.6
	15	Prądnik (Wisła)	scarp-foot, fissure, karst, rheocren	6.5–13.0
Northern Part	16	Rak (Warta)	scarp-foot, rheocrene	115–150
	17	Białka (Pilica)	scarp-foot, fissure, karst, rheocrene	25.0–35.8
	18	Białka (Pilica)	scarp-foot, terrace, fissure, rheocrene	30.0
	19	Białka (Pilica)	scarp-foot, descending-ascending, fissure, rheocrene	47.0–109.0
	20	Wiercica (Warta)	near channel, scarp-foot, descending-ascending, encased	230-1440
	21	Wiercica (Warta)	hillsde, descending, fissure, karst, rheocrene	30.0
	22	Wiercica (Warta)	hillside, descending, fissure, karst, reocrene	30.0
	23	Czarka (Warta)	hillside, fissure, limnorheocrene	20.0–47.0
	24	Leśniówka (Warta)	hillside, fissure, rheocrene, partly encased	46-100
	25	Biała Przemsza (Przemsza)	valley, rheocrene, in bottom of artifical pond	*ca.* 50.0

* Classification based on spring morphology, hydrogeology and hydrobiology.

Fig. 1. Localisation of the study area (Cracow-Częstochowa Upland) and the studied springs with their local names in English (and in Polish): 1 – Near Shop Spring (Przy Sklepie), 2 – Near School Spring (Przy Szkole), 3 – In Meadow Spring (Na Łące), 4 – Geophysicists' Spring (Geofizyków), 5 – Russian Spring (Ruskie), 6 – Near Road Spring (Przy Drodze), 7 – Spring under the Hornbeam (Spod Graba), 8 – Scout's Spring (Harcerza), 9 – Spring in Sułoszowa (W Sułoszowej), 10 – Spring under the Bludgeon (Pod Maczugą), 11 – Spring near Wernyhora`s Rock (k. Skały Wernyhory), 12 – Młynnik Spring (Młynnik), 13 – Joyfull Spring (Radości), 14 – Love Spring (Miłości), 15 – Spring in Pradnik Korzkiewski (W Prądniku Korzkiewskim), 16 – Łakotnik Spring (Łakotnik), 17 – Under the Rock Spring (Spod Skały), 18 – Near River Spring (Przy Rzece), 19 – Madam Halska's Spring in Sokolniki (Pani Halskiej w Sokolnikach), 20 – Blue Springs (Niebieskie źródła), 21 – Elizabeth's Spring (Elżbiety), 22 – Zygmunt's Spring (Zygmunta), 23 – Spring under the Bearch (Spod Brzozy), 24 – Spring in Jaworznik (W Jaworzniku), 25 – Spring in Strzemieszyce (W Strzemieszycach).

more than 100 m deep. Two of the studied springs (Nos 1 and 2) are greatly modified by man in order to provide drinking water for humans or cattle – they are partially enclosed within small covered concrete boxes that are open for access on one side. Some of springs are encircled by concrete well-heads. Spring No 14 has an underground water intake (in a pipe) and its effluent is situated in a concrete overflow channel. The outflowing water falls down 1 m creating a small pool from where sediments were collected. Spring No 25 was chosen as a reference site since it is fed by fissured Middle Triasic limestone and dolomites and thus differs from the rest of the studied springs.

3. METHODS

Each spring was sampled four times: in February, May, August, and October of 2003. Temperature and pH were measured *in situ*. Water for oxygen analysis was taken in glass bottles and measured in the laboratory by the Winkler method. Water samples were taken in plastic bottles and the remaining analyses were performed in the laboratory according to American Public Health Association (1992). The concentrations of Ca and Mg were measured by complexometric titration, Cl by mercuric nitrate titration, sulphates by a nephelometric method, total hardness by a method using versenate, alkalinity by titration of the sample with 0.1 M HCl and methyl orange to pH 4.5, oxidability with $KMnO_4$, nitrates using a colorimetric method with phenol disulfonic acid, ammonium by a method based on Nessler`s reagent, and phosphates spectrophotometrically (with ammonium molybdate and ascorbic acid as a reducing agent).

Two samples of the sediment were collected from each spring with a polyethylene corer (diameter 4 cm), which was pushed into the substrate to a depth of 5 cm. It was not possible to take sediment samples from the encased spring No 1, or from the spring No 4 in August and October (it had dried out), or from spring No 20 in February. The sediment samples (without the benthic invertebrates which was sorted out under the stereoscopic microscope) were dried (105°C) to a constant mass, weighed and ashed (3h, 550°C) to determine loss on ignition (LOI). The results were expressed as % of organic matter. Altogether 185 sediment samples were collected.

Grain size fractions were determined using the aerometric method. The fractions determined were: sand (1.0–0.1 mm), silt (0.1–0.02 mm) and clay (<0.02 mm).

Water chemistry and environmental data were analysed using discriminant function analysis with Statistica 6 software by StatSoft®.

4. RESULTS

In the majority of the springs studied the temperature remained relatively constant during the year. The mean (range) temperature was 8.8 (7.2–9.5)°C (Fig. 2A) in the springs of the southern Upland. Only in the encased springs, Nos 1, 12 and 14 the temperatures were higher: 10.3 (in autumn), 10.1 and 9.9°C (in spring). In the northern springs mean temperature was a little higher: 9.4°C (8.0°C–10.3°C) what was an effect of deeper water circulation layers of those springs. Only in the encased spring No 20 the water temperature reached 14.4°C in summer.

All the springs studied were alkaline with pH varying from 7.0 to 8.3, although the southern springs had a smaller annual amplitude of pH fluctuations, while in the northern springs the annual range of pH was much greater (Fig. 2B). The same tendency was observed for alkalinity (2.6–5.3 mval dm^{-3}) (Fig. 2C).

Water in the studied springs had high conductivity and total hardness (Table 2). Only the conductivity and total hardness values of spring No 25 were much higher than in the other springs (630 $\mu S\ cm^{-1}$, 8.2°N, respectively). The magnesium content was low in almost all the springs studied, with a mean value of 1.2 mg dm^{-3}, except for spring No 25 with 12.3 mg dm^{-3} (Table 2). A similar situation was observed with the sulphates concentration: the mean value of which was 14 mg dm^{-3} for all springs, but in No 25 it reached 74.5 mg dm^{-3}. Oxygen saturation levels were quite low in all the springs studied: 83% O_2 in the southern and 78% O_2 in the northern springs. The concentration of organic matter represented by oxidabil-

Table 2. Physical and chemical parameters in studied springs from South (Nos. 1–15) and North (Nos. 16–25) parts of Cracow-Częstochowa Upland (Fig. 1). Mean and range value for analysed springs is given.* – Min, max and mean value without spring No 25.

Variable		South			North		
		min	max	mean	min	max	mean
Temperature	°C	7.2	10.3	8.8	8.0	14.4	9.4
pH		7.4	8.3	7.8	7.0	8.2	7.9
Alkalinity	mval dm^{-3}	3.7	4.8	4.3	2.6	5.3	3.9
Conductivity	μS cm^{-1}	319.3	554.9	423.6	302.7	453.3	355.2*
Total hardness	°N	4.1	6.5	5.1	3.7	6.0	4.2*
Calcium	mg Ca dm^{-3}	26.4	42.5	34.4	24.7	43.6	25.3
Magnesium	mg Mg dm^{-3}	0.0	4.1	1.2	0.2	3.2	1.3*
Sulphates	mg SO$_4$ dm^{-3}	1.4	18.5	14.8	3.3	32.5	14.2*
Chlorides	mg Cl dm^{-3}	0.4	4.5	1.0	0.5	17.7	25.3
Oxygen saturation	O$_2$ %	63	105	82	0.0	125	78
BOD$_5$	mg O$_2$ dm^{-3}	0.6	4.2	1.6	0.2	5.1	0.9
Oxidability	mg O$_2$dm^{-3}	0.2	1.4	0.5	0.0	1.3	0.4
Ammonium	mg NH$_4$ dm^{-3}	0.1	0.7	0.2	0.2	4.2	0.3
Nitrates	mg NO$_3$ dm^{-3}	1.2	6.9	3.4	1.44	7.0	6.6
Phosphates	mg PO$_4$ dm^{-3}	0.1	0.5	0.3	0.22	1.4	0.4

ity and BOD$_5$ was low (average 0.4 mg and 1.3 mg dm^{-3}, respectively). The Cl values in the southern springs had a small annual amplitude of fluctuations, while in most of the northern springs there was much greater fluctuation (Fig. 2D). The mean ammonium concentration in the southern springs was 0.25 mg NH$_4$ dm^{-3} (Table 2); only the springs Nos 1 and 2 had an elevated value in spring (0.4 mg dm^{-3}) and in spring No 9 – it was up to 0.7 mg dm^{-3} in summer. Spring No 23 in the northern Upland had an ammonium value of 4.2 mg NH$_4$ dm^{-3} in autumn. The nitrates concentrations were high, with the maximum value noted in the northern area (ca. 7 mg NO$_3$ dm^{-3}) (Fig. 2E). Phosphates concentration was also high and varied from 0.13 to 1.38 mg PO$_4$ dm^{-3}. Elevated values (0.39–1.04 mg PO$_4$ dm^{-3}) were noted in almost all the north Upland springs in summer, and also in spring No 23 in autumn (1.38 mg PO$_4$ dm^{-3}) (Fig. 2F).

Most of the sediment samples from the southern Upland springs consisted of fine material and their organic matter content ranged from 1.3 to 11.8%, on average 4.1% (Fig. 3). In sediments from the northern Upland springs the sand fraction dominated and organic matter content was very low (range 0.1–3.1%, average 0.9%).

Springs with three different ranges of discharge (1. – <8.9 l s^{-1}, 2. – 9.0–30.5 l s^{-1}, 3. – >30.5 l s^{-1}) (see Table 1) were clearly identified with the discriminant function analysis based on their physical parameters. The springs were divided into three groups with 93% agreement (Fig. 4). All the classifications based on the other environmental parameters (encased/not encased springs, type of substratum, temperature) and water chemistry data (pH, oxygen, alkalinity, nitrates and phosphates, organic matter in sediment) were less accurate than those based on discharge.

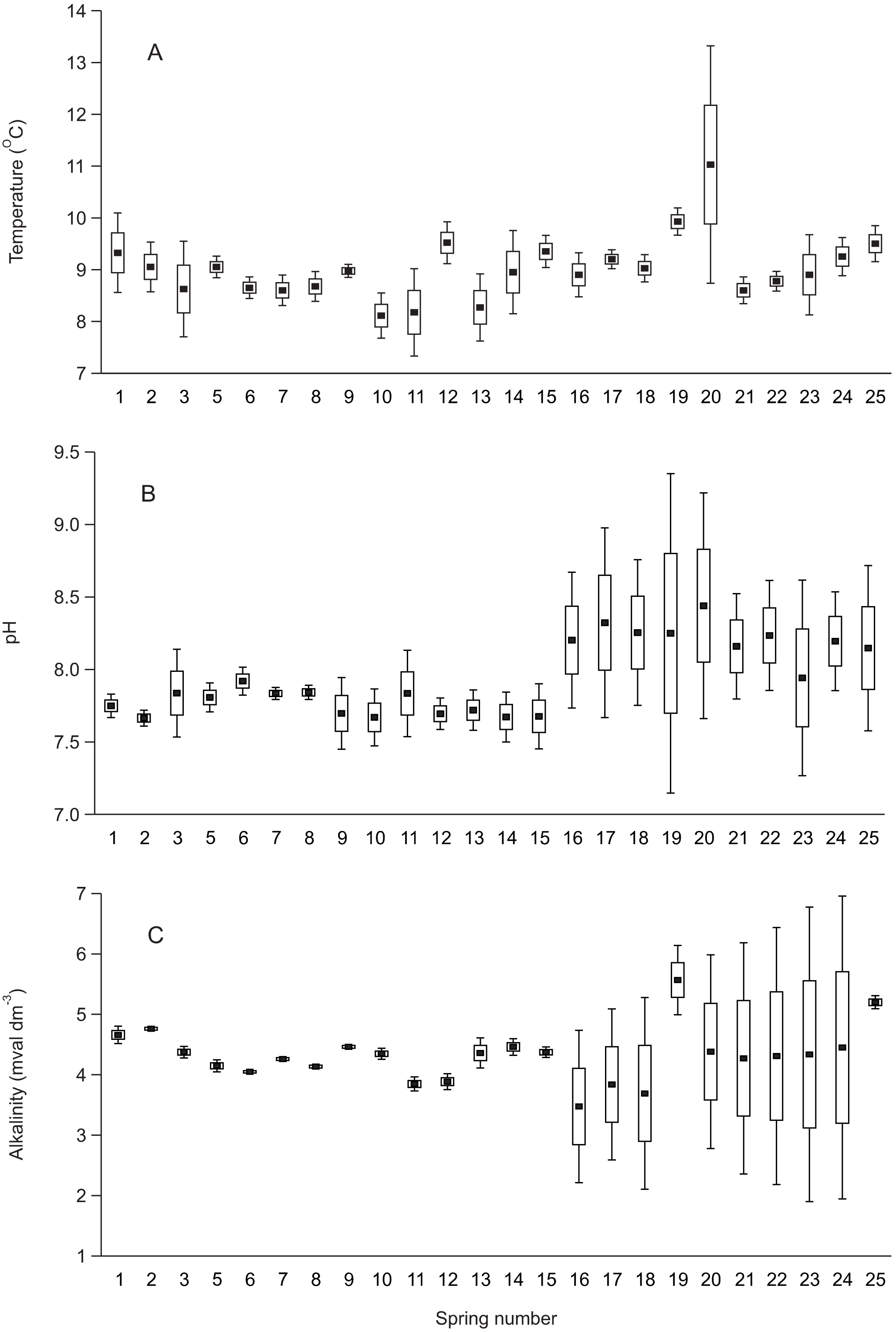
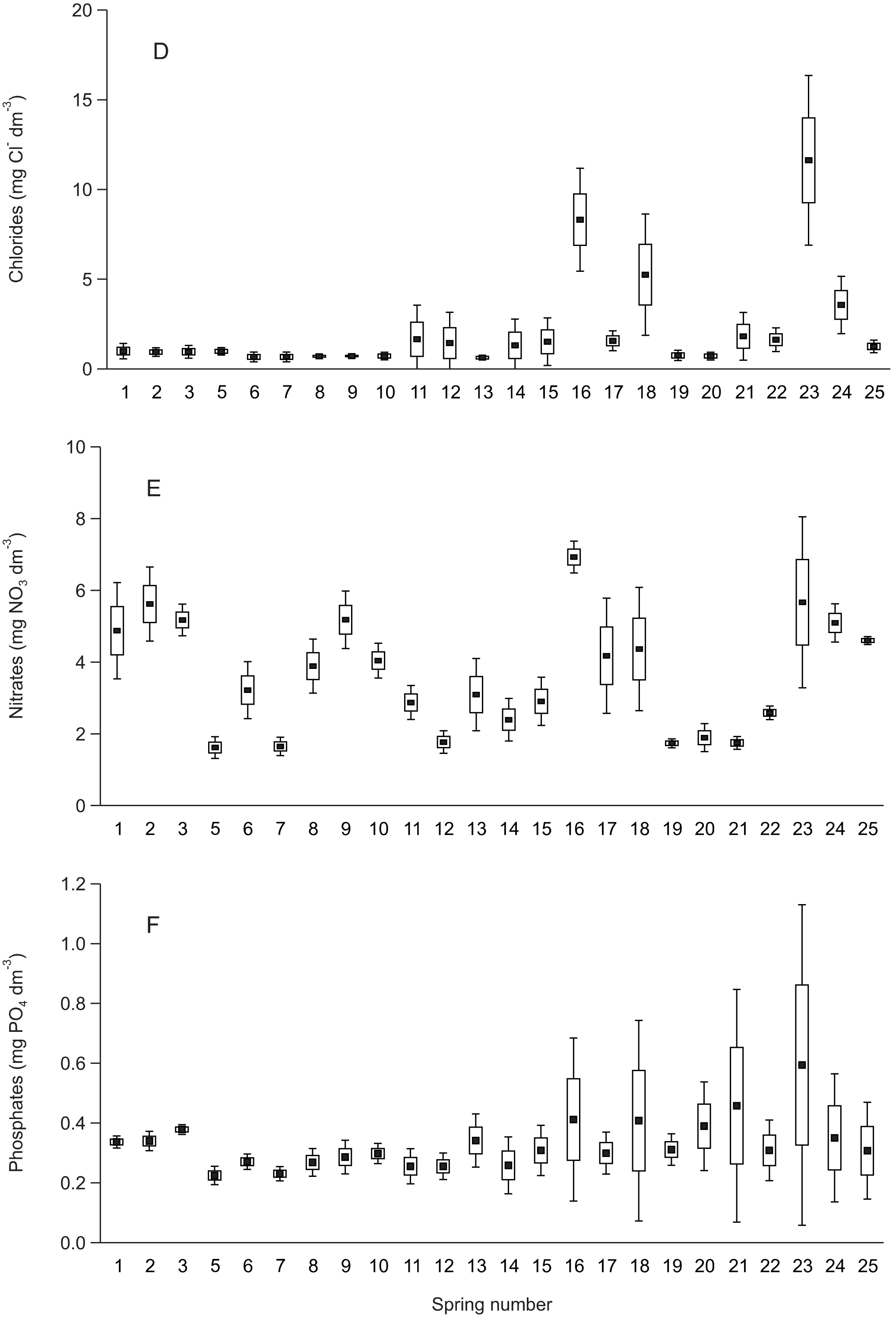


Fig. 2. Mean annual values (ranges and SD) A – water temperature, B – pH, C – alkalinity, D – chlorides, E – nitrates, F – phosphates in the springs waters (spring number – see Fig. 1, Table 1).


D
Chlorides (mg Cl⁻ dm⁻³)
0
5
10
15
20
1 2 3 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
E
Nitrates (mg NO₃ dm⁻³)
0
2
4
6
8
10
1 2 3 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
F
Phosphates (mg PO₄ dm⁻³)
0.0
0.2
0.4
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Spring number

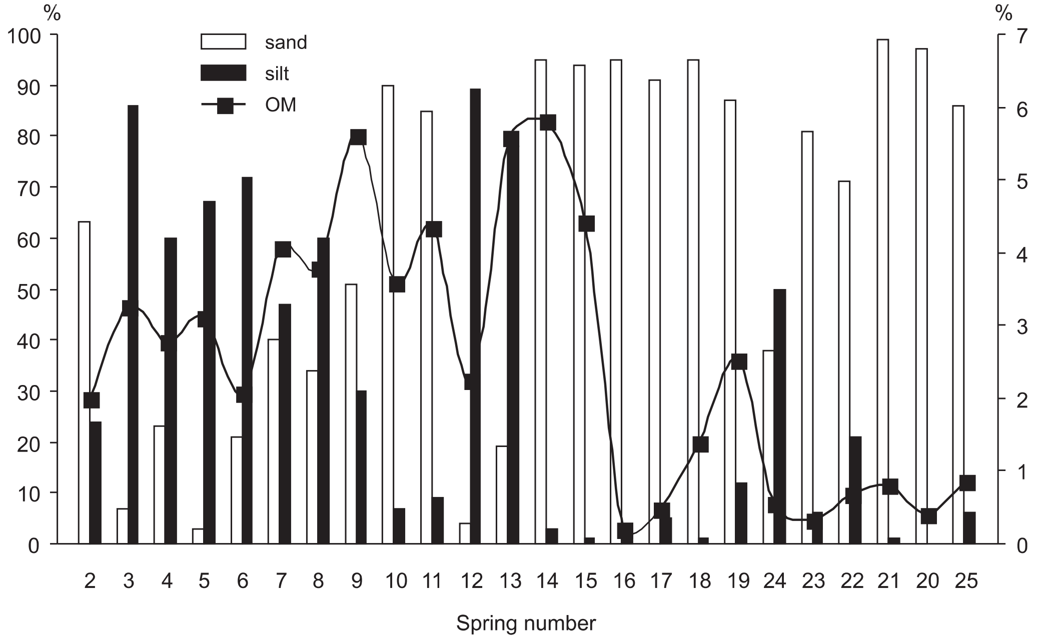

Fig. 3. The percentage of sand and silt fractions (left axis) and organic matter content (%) (right axis), in the sediment of the studied 1–25 springs. (see Fig. 1, Table 1).

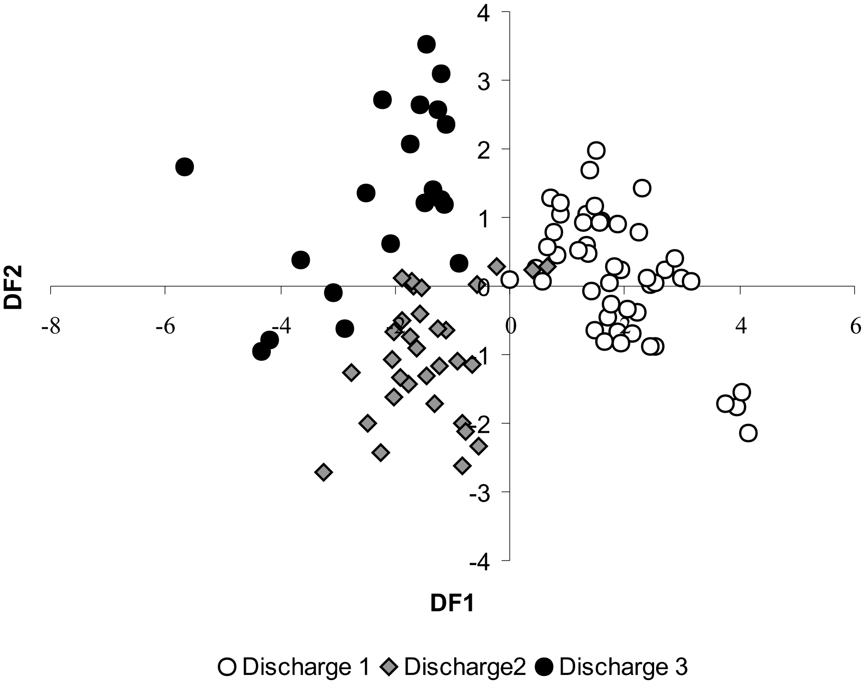

Fig. 4. The results of discriminant function analysis showing the classification of springs with different discharge values 1 –<9 l s^{-1}, 2 – 9–30 l s^{-1}, 3 – >30 l s^{-1}.

5. DISCUSSION

Annual variations in water temperature did not exceed 4.1°C, which is the unique and biologically important feature of many springs (van der Kamp 1995). In the northern Upland the slightly higher mean temperature was an effect of deeper water circulation layers of those springs (Chełmicki 2001). Higher temperatures of water in encased springs, resulted from the effect of air temperature on the standing water. The pH of studied waters of the southern part of Upland did not vary considerably during the year, in contrast to that of the springs in the north whose fluctuations resulted from the decreasing level of underground water in this part of the Upland during 2003 (A. Tyc, personal comm.).

The spring waters, with no human influence, contained low amounts of nitrogen in the forms of ammonium and nitrites but the value of nitrates was usually high (1–5 mg NO_3 dm^{-3}), that is typical for subterranean waters (Gibert *et al.* 1994) and noted in springs from the Cracow-Częstochowa Upland (Różkowski 1996, Chełmicki 2001) as well as in other studied springs (Chafiq and Gibert 1993, Webb *et al.* 1998, Smith and Wood 2002). Higher nitrates concentrations were considered to be mostly the result from anthropogenic impact like point source pollution from animal farming and lack of central village sewage systems within the alimentation area of the aquifer as well as the usage of artificial fertilizers. Farmland areas prevail in the region with arable land dominating (80–90%). However, the mostly small-sized farms (typically a few hectares) are engaged in a rather low-intensity activity with little fertilizer use (90 kg NPK ha^{-1} in 2000) (Chełmicki 2001, Siwek and Chełmicki 2004). Springs of the Cracow-Częstochowa Upland located within villages and regions with intensive recreation had 20–60 mg NO_3 dm^{-3} (Różkowski 1999). Springs from the southern part of the Upland with elevated value of nitrates (No 1, 2, 9, 10, 11) were located mostly in small villages, where organic input from animal farming was evident, together with poor sanitary conditions in the countryside – lack of central sewage disposal systems and ground leaking of sewage and manure tanks (Siwek and Chełmicki 2004). It had also additional negative influence on PO_4 concentration which values were elevated in springs No 1 and 2 that was stated already in the 1990s (Chełmicki 2001*)*. Increased tourism of this area resulted in nutrient pollution of many springs (e.g 0.7 mg NH_4 dm^{-3} in summer and 0.5 mg NH_4 dm^{-3} in autumn in spring Nos 10) as well as their devastation (Tyc 2004). Also extensive farming in catchments of springs from the north part of the Upland (Nos 16, 17, 24) resulted in the relatively high concentrations of nitrates in those springs. The rise in mineral forms of nitrogen in all springs mentioned above was influenced by human activity and had been observed already in the 1960s (Alexandrowicz and Wilk 1962, Różkowski 1996) and in the 1990s (Różkowski 1996, Chełmicki 2001).

In springs Nos 17, 18 and 24 the "thaw effect" can be observed i.e. an increase in the discharge is accompanied by an increase in nitrates usually two months after the beginning of the snow melting period (Tyc 1997). Spring No 23 has a very small catchment which water circulates in a shallow aquifer, so the spring has high amplitude of discharge which decreased drastically in the autumn of 2003. The large amount of allochthonous matter – birch leaves (the spring is named "Under the Birch" Fig. 1) – fell into a small pool and decomposed which caused the rise in ammonia and PO_4 content at this time. The elevated concentrations of Cl in this spring as well as in springs No 16 and 18 might be a result of intensive tourism activity which also produced the mechanical degradation of those springs.

There was no agriculture activity or human settlements in the discharge areas of springs No 19, 20, 21 and 22, located in the northern part of the Upland and it is why the concentrations of the nitrates were low. Additionally, springs No 19 and 20, situated on the eastern border of the Cracow-Częstochowa Upland, are fed with waters from deep circulation. This part of the Upland is covered by impermeable sediments which protect those springs from the impact of human pollution (Dynowska 1983).

Spring No 25, treated as an "out of group" site, has a different feeding layer from the other springs included in this study and its outflow is located in the site of a former Zn-Pb ore scrubber (19th Century). High concentrations of sulphates in its waters originate from the oxidation of $ZnSO_4$ and $PbSO_4$. Also, high Ca, total hardness and conductivity values reflect the affluent level and the type of Triassic circulation, there is a more dispersed water system compared with the circulation occurred in Jurassic rocks. Water is in contact with the rock for longer, which results in higher content of elements deriving from the dissolved rock (Dynowska 1983, Chełmicki 2001). The increased nitrates concentration in this spring was also due to its locality – in the middle of a village without a proper sewage disposal system.

The results of investigations demonstrate that springs water are very clean since according to the underground water classification the concentrations of e.g. nitrates and sulphates correspond to the 1^{st} or 2^{nd} class of ground water quality.

In springs, the amounts of organic matter are dependent on the input rate, channel morphometry, biotic processing rates, retention and discharge rate (Smith and Wood 2002). In the current investigations the amount of organic matter in the sediments was low (0.9%), particularly in springs located in the northern area, where the sand fraction prevailed and a high discharge resulted in immediate flushing out of leaf litter, abundant in the immediate surroundings. Only spring No 23 exhibited a higher content of organic matter (2.9%) which was connected with the occurrence of a stony loam in its surroundings. Sediments composed of a silt-clay fraction with higher content of organic matter were found in most southern Upland springs, where the low discharge favored accumulation of organic matter in the sediments. The studies of karstic springs sediments by Chafiq and Gibert (1993) showed the importance of fine sediments in the retention of organic matter. Therefore we may assume that the amount of organic matter in the studied spring sediments depends mainly on their flow characteristics (Smith and Wood 2002).

All the springs studied can be clearly differentiated based on the variability of their discharge which may lead to significant temporal variability in aquatic community (Smith and Wood 2002, Smith *et al.* 2003). Further biological results reveal the relationships of different chemical and physical factors to macroinvertebate community abundance and structure.

Thus, the main conclusions from this research are as follows:

- the temperature at the studied springs was low and varied little throughout the year,
- pH, alkalinity, nitrates and phosphates concentrations in the water were more stable during the year in springs located in the southern part of the Upland while they varied strongly in springs of the northern part. Those differences were strongly related to springs hydrogeology (e.g. type and depth of water level, discharge value),
- high nutrient concentrations were recorded in some springs with catchment areas subjected to anthropogenic influences (farming, leaking sewage tanks near farm buildings, fertilization),
- the sediments of the springs differed in terms of grain size and organic matter content: in the south part of the Upland silt dominated, with 4% organic matter, while in the northern part the sand fraction, with a lower content of organic matter(0.9%) was predominant,
- the temporal variability of the discharge was the only one of the abiotic parameters analysed that was found useful for grouping of the studied springs.

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