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Springs in South-Central Poland – changes and threats

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Springs are an attractive and dynamic element of natural environment, as well as an important part of cultural landscape. Numerous studies have been undertaken in the Krakowsko-Wielunska and Miechowska Uplands for over 40 years. As many as 246 springs were mapped in the 1970's and investigations have continued to the present. These have considered the type of spring, discharges, chemical composition of water, and spring surroundings including the species composition of habitats. The long period of observations has revealed changes of spring properties due to natural and anthropogenic factors. Only 38% of investigated springs maintained their natural character. The majority were completely devastated and overwhelmed. Waste was found in more than 20 springs. Also a decrease in spring discharge of about 10–30% compared to the 1970's and 1990's was noticed. But there was no clear common tendency of improvement or degradation of water quality in the whole area. However the problem of spring water pollution still persists mostly due to agriculture activity and long distance air pollution transport. Interdisciplinary research and collaboration of scientists with local authorities seems to be the only way to solve the problem of spring water quality and adequate management of their surroundings. Results of the studies have provided knowledge and a basis for concrete management application.

Introduction

Changes in climate and land use have significant impacts on the natural environment on the local, regional, and global scales. Water resources – surface and groundwater water bodies – influenced by these changes appear to be the most important for human kind. While changes of surface waters are quite well recognized, the most of groundwater changes are poorly known. As springs constitute a very important component of water cycle, they can reflect changes in physical and chemical quality and quantity of groundwater.

In general, springs reflect local conditions of the catchment, such as: precipitation, air temperature, conditions of infiltration and percolation (land cover, soils) as well as groundwater aquifer properties. Springs are certainly valuable, they are recognized as important, rare, and globally threatened ecosystems (Springer and Stevens, 2009; Chelmicki et al., 2011). They are considered to be hotspots of biological and cultural diversity and the presence of endangered or unique species. Hence they are objects of scientific interest mostly because of ecological, educational, cultural and aesthetic value (O'Halloran et al., 1994; Grey, 2003; Bascik et al., 2008). They are included as an element of geodiversity and geological heritage in the "Recommendation on conservation of the geological heritage and areas of special geological interest" adopted by the Committee of Ministers of the Council of Europe in May 2004 (Dingwall et al., 2005). Particular scientific attention is paid to springs used as a source of drinking water as well as to those used in agriculture and power generation (Kresic and Stevanovic, 2010; Stevanovic and Eftimi, 2010).

Springs may demonstrate the fundamental principles of water cycle in subsurface and surface environment and they also reflect environmental and land use changes (Bonacci, 1987, 1993; Siwek, 2004; Zuber et al., 2008). These changes can affect the physical and chemical properties of springs, thus springs may be recognized as natural indicators of environmental pollution (Chelmicki and Siwek, 2001; Bascik and Chelmicki, 2004; Ciszewski et al., 2004; Siwek and Chelmicki, 2004). Because of their sensitivity, they reflect anthropogenic pressure as well as natural changes and the evolution of natural environment.

Karst regions are particularly vulnerable to the impact of agriculture, deforestation, changes in grazing intensity and changes from pasture to tillage, application of fertilizers, and pesticides and storage of farm wastes. The occurrence of point recharge in closed depressions and swallow holes, the thin, patchy soil cover found in karst areas, the presence of epikarst and the occurrence of conduit flow within karst aquifers, all contribute to the potential impact on water quality; including suspended sediment, nitrate, phosphorus, pesticides, and microbial pathogens in karst regions (Coxon, 2011). For instance there are strong evidences of non-point sources of nitrate in headwater karst springs. Thus, nitrification of soil ammonium is recognized as the main process responsible for the nitrate increase in north Florida in years in which the rainfall level was below normal. Concentration of nitrate declines downstream (Albertin et al., 2012). There are regions, where cattle activity in farms affects nitrate concentrations in groundwater aquifers. Groundwater is particularly vulnerable where agriculture, thin free-draining soil and karst aquifers coincide. For example, there is a linear relationship between the nitrate concentration in karst springs (as 12–16 mg/L) and the percentage of agricultural land in the karst Appalachian Region. Median nitrate concentration is increased about 0.19 mg/L in agricultural land (Boyer and Pasquarell, 1995). The combination of land use, nutrient sources and mobilisation and/or dilution during storm events may lead to various nutrient responses in karst springs. These responses have consequences in the delivery of nitrate to surface receptors (Huebsch et al., 2014).

Investigation of springs shows increasing dissemination of pharmaceutical residues in the environment, such as in springs in Bavaria. These compounds present a high potential for water and soil contamination. Pharmaceuticals infiltrate through sinkholes and small streams into the karst system and then become present in springs, being discharged in concentrations – in case of diclofenac – between 3.6 and 15.4 ng/L. However, ibuprofen has been rarely detected in groundwater. Pharmaceuticals comprise one of the few groups of chemicals that are specifically designed to act on living cells. Chronic exposure to them adds to the effects of other chemicals in the environment and might be leading to synergistic effects. The results of research suggest that both diclofenac and ibuprofen move into the fractured system of karst rocks and go into the storage. Research using isotopes and tracers allows assessment of the mean transit time of the water in karst aquifer and to characterize the hydrogeological flow path in the groundwater system. A mean ^{3}H transit time of 4.6 years for the fissured-porous karst aquifer has been determined, whereas the fast flowing water in the conduit system showed a mean transit time of days. Thus pharmaceuticals may appear in the surface water soon after entry. Dilution is a prime control on the concentrations of pharmaceuticals in the fractured karst system, whereas biodegradation is rather less important (Einsiedl et al., 2010).

Widespread pesticide application in cropland, orchards and other agricultural activities has caused worldwide risks for global surface waters. For instance the seasonal variation of pesticide (and nitrate) concentration is generally similar for two springs representing various short-term responses to the rainfall in northern Alabama: a shallow flow system with a relatively short average ground-water residence time and a deeper flow system having a longer average ground-water residence time. From about November to March, when recharge rates increase, nitrate and residual pesticides in the soil unsaturated zone, as well as those stored within the aquifer are transported to the spring discharges. Because of the increase in recharge, pesticide loads discharged from the springs during the winter were comparable to the loads discharged at the springs during the growing season (Kingsbury, 2008).

Septic tank leachate presents a major threat to quality of groundwater at a local scale. Significantly higher potassium, boron, chloride, dissolved organic carbon, and sulfate concentrations, may indicate the influence of septic-tank effluent. Impacts on groundwater quality from septic systems were very evident e.g., for the Northern High Plains aquifer (USA) and were associated with the number of housing units using septic tanks, high permeability of overlying sediments, mostly oxic conditions, and shallow aquifers. Little or no influence from septic systems was found in water samples from the deeper public-supply aquifer. The Cl/Br ratio is a useful first-level screening tool for assessing possible septic tank influence in water from shallow groundwater (< 20 m) with the range of 400–1100 (Panno et al., 2006; Katz et al., 2011). A potential source of chemical and bacterial contamination of springs are on-site waste water treatment systems. Most of the effluents contain relatively large concentrations of sodium, chloride, nutrients (nitrogen, phosphate, and potassium), and enteric bacteria. These contaminations are typical for areas with highly susceptible aquifers such as the sinkhole plain of southwestern Illinois. Chemicals and enteric bacteria may pose a health hazard to those who come into contact with them (Panno et al., 2007).

Overexploitation of groundwater leads to a decline in aquifer levels. In case of Israel, it has reached the point where several of the springs supplying the streams in the country ceased to flow (Tal and Katz, 2012). Flow in a full two-thirds of all monitored springs in Israel was severely reduced and/or actively witnessing declines. Even nature reserves in the northern Galilee region, where cool flow was present throughout the year, are frequently “bone dry” during the summer season. Only the headwaters of the Jordan remained with significant shares of natural flow supporting ecosystems (Katz and Tal, 2013).

The negative influence of human activity on springs is widespread in many parts of the World. There has been a lack of synthetic research related to the springs in Poland at a region-wide scale. Therefore this paper makes a comparative analysis and evaluation of long-term changes of almost 250 set of springs in the Krakowsko-Wielunska and Miechowska Uplands (southern Poland), which have been observed for over 40 years. This study highlights the impacts of human activity on the environment, as well as the anthropogenic changes to the springs. The research was designed to advance understanding of spring responses to environmental and land use changes as well as to help to determine the vulnerability and resilience of springs to such changes.

Study area

The springs are located in the Krakowsko-Wielunska and Miechowska Uplands, southern Poland (East-Central Europe). The area covers approx. 8000 km^2. These uplands consist of a 130 kilometres range of hills orientated from SSE to NNW. They form the headwaters of the main left tributaries of the Vistula River: Przemsza, Rudawa, Pradnik, Dlubnia, Szreniawa, Nidzica and Pilica, and the right tributary of the Oder River – Warta. With the exception of the Carpathian Mountains, the uplands comprise the main headwater area of the country.

The investigated uplands are underlain by the Silesia-Cracow monocline and the Miechow basin sedimentary rocks (Fig. 1). The Jurassic limestone formation constitute a monocline gradually “submerging” under younger Cretaceous and Tertiary formations towards the ENE. The Triassic, Jurassic, and Cretaceous carbonate rocks: marls, rocky limestones, platy limestones, chalky limestones, are efficient groundwater aquifers. The hills consist mainly of Jurassic limestones in the west and Cretaceous marls in the east, rising generally up to c. 400 m a.s.l. and locally – as scattered residual hills – up to 500 m a.s.l. The upland regions are on average 100–150 m higher than the surrounding areas. The entire upland structure has numerous tectonic faults, providing natural boundaries to the various horst and graben structures, particularly in the south of the region, near Cracow. The uplands are cut by a network of river valleys – with numerous rocky features on the slopes, karst gorges and hilltops (residual hills).

In the Jurassic part of the region a three-tier aquifer has developed corresponding to the Upper, Middle and Lower Jurassic formations. The most important of these is the karstic-fissure-porous aquifer of

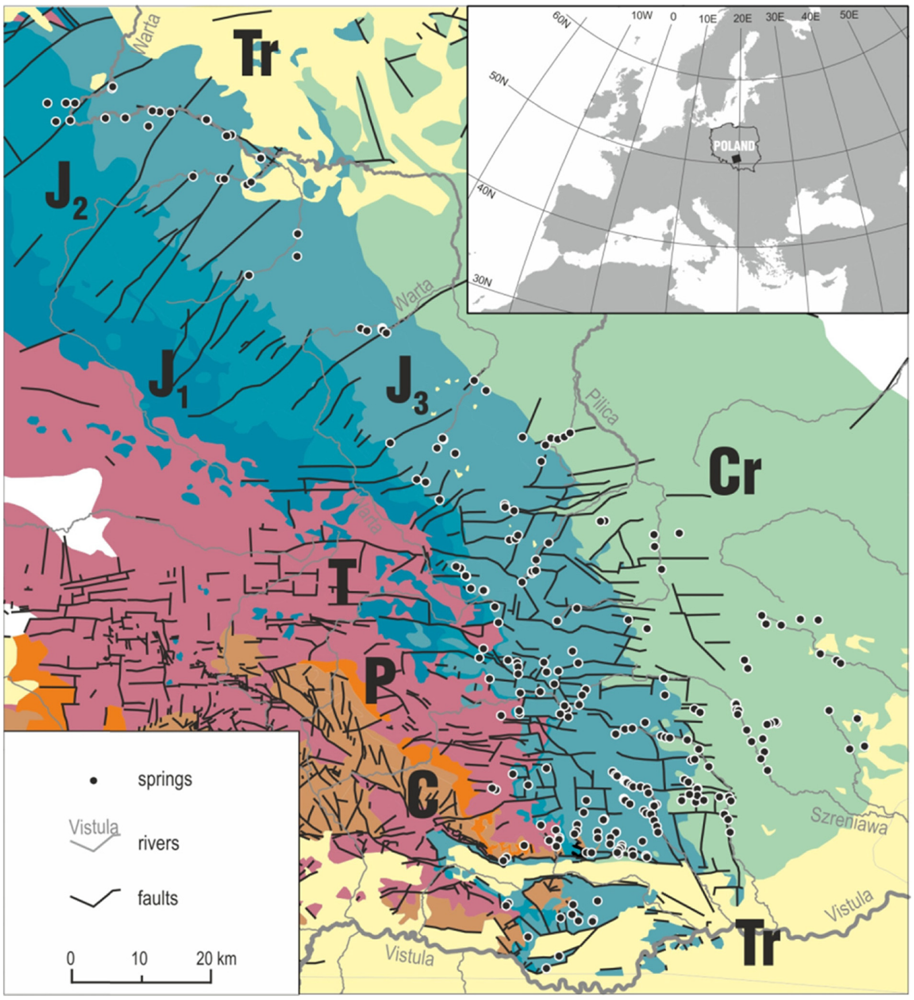

Figure 1. Simplified geological map of the Cracow-Czestochowa and Miechowska Uplands without Quaternary strata (after Kaziuk,1978; Haisig, 2007, simplified). Tr – Tertiary (silts), Cr – Cretaceous (marls), J_{1-3} – Jurassic (limestones), T –Triassic (dolomites, limestones), P – Permian (tuffs, volcanic rocks, conglomerates), C – Carboniferous and Devonian (carbonates).

Upper Jurassic (Rozkowski, 2006; Paczynski and Sadurski, 2007). It supplies numerous karst and fissure-karst springs located in valley floors. A similarly sized aquifer is found in Cretaceous marls to the east. This aquifer is drained by a smaller number of fissure springs with capacities periodically exceeding 100 L/s.

The Krakowsko-Wielunska and Miechowska Uplands are exposed to heavy industry air pollution and mining activity in the adjacent Upper Silesia conurbation and similar activity_in towns of Olkusz, Cracow and Czestochowa. Cracow (with a population of c. 750,000) has a strong industrial sector dominated by the large steel plant in the eastern part of the city. The Upper Silesian conurbation (population of approx. three millions) is one of Europe's largest mining (hard coal) and heavy industry (steel) regions and, consequently, is also a major polluter. The town of Olkusz and its mining industry (lead and zinc) plays a similar part, as well as the steel industry of Czestochowa, but in that case to a lesser extent. For these reasons the investigated area has some of the areas most exposed to acid rain in Europe. Therefore precipitation is among the most serious sources of pollution of surface and groundwater.

Also, mining activity in the Silesia and Olkusz regions, with water pumping, causes cones of depression which extends well beyond the mine boundaries into surrounding, including upland, areas Additionally, in local scale, a drawdown occurs also around drinking groundwater intakes.

The Miechowska Upland is primarily used for agriculture (Table 1). However, the contribution of farming in the Krakowsko-Wielunska Upland to the local economy is declining which is a usual nationwide tendency in rural communities. The smallest farms (typically a few hectares) are engaged in rather low-intensity activity with little fertilizer usage (90 kg NPK/ha in 2000).

This upland area is dominated by farmland (70–80%) with moderately sized crops; most acres under in crops are in wheat and barley, followed by white beet and vegetables. Fertilizer usage currently ranks between 70–120 kg NPK/ha but in the 1980s the usage was twice as large as at present. Even so, farming remains a local, large-area source of pollution in the Miechowska Upland.

A serious problem in rural areas in both Uplands is posed by unregulated water and waste water management. During the last 30 years, the regions experienced a rapid expansion of potable water supply systems that greatly outstripped sewage systems. Thus, groundwater was exposed to pollution from inadequately insulated sewage tanks and "wildcat" sewage dumping directly into rivers. Additionally, it is probable that much untreated household waste water was discharged directly into the environment.

Table 1. Land use (%) in the Krakowsko-Wielunska and Miechowska Uplands (based on CORINE 2006 database)

	DL	NI	PI	PK	PR	PZ	RU	SZ	WA
Settlement	6.7	3.5	2.2	5.3	9.5	12.6	9.0	4.4	4.6
Industrial	3.5	0.1	0.1	1.7	2.2	9.1	2.1	0.2	1.4
Agricultural	81.2	89.5	57.3	72.3	75.0	40.1	64.2	89.3	64.1
Forests	8.5	6.8	39.5	19.7	13.3	36.5	24.4	6.0	29.5
Other	0.1	0.1	0.8	1.0	0.0	1.8	0.3	0.2	0.4

The river catchments: DL – Dlubnia, NI – Nidzica, PI – Pilica, PR – Prądnik, PZ – Przemsza, RU – Rudawa, SZ – Szreniawa, WA – Warta, PK – other small basins of Vistula tributaries.

The Uplands are a touristic and recreational destination for the population of Cracow, Upper Silesia and other cities in the region. Part of the area is legally protected as the Ojcowski National Park (21.5 km^2), a complex of Landscape Parks (700 km^2), and Natura 2000 areas. 38 springs are individually protected as natural monuments. These constitute 30% of all springs legally protected as natural monuments in Poland (Bascik et al., 2009). Most are located in the south of the region and were established in 1987 following research by I. Dynowska (Drzal and Dynowska, 1981) and in 2002 as a result of research conducted by W. Chelmicki (Bascik and Pociask-Karteczka, 2001, 2002).

The beauty of the landscape conflicts with the neighbourhood of big cities and industrial centres with increased pressure for housing and leisure development. In recent years, the region has experienced a significant expansion of new settlements accompanied by all required infrastructure (water, heat and power systems, road network, shopping centres, etc.).

Methods

In September 2011 the Department of Hydrology of the Institute of Geography and Spatial Management of the Jagiellonian University started a research project continuing the earlier research of Prof. Irena Dynowska in 1970s (Dynowska, 1983). These were led between 1999–2000 by Prof. Wojciech Chelmicki (Chelmicki, 2001). Subsequent research in 2011–2013 considered springs as a complex systems and was, therefore, interdisciplinary (including hydrologists, hydrogeologists, hydrobiologists and landscape management specialists). The results of these studies have provided knowledge that will be a basis for management of springs in the future.

The 246 springs, previously mapped by the team of Prof I. Dynowska and repeated in 1999–2000, were again investigated in 2011–2013. The new survey considered their type, discharge (based on volumetric or current meter measurements), location (GPS), character of flow, surroundings, and their physical and chemical characteristics. Specific Electric Conductivity (SEC), pH, water temperature and discharge of springs were measured in the field. Ions: Ca^{2+}, Mg^{2+}, Na^+, K^+, NH_4^+, Li^+, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, NO_2^-, PO_4^{3-}, F^-, Br^- were determined in the Hydrochemical Laboratory of the Institute of Geography and Spatial Management by ion chromatography methods (DIONEX ISC2010). Botanical studies and bio-monitoring of selected springs was also carried out. Diatoms were chosen as a bio-indicator of water quality.

Discharge of springs

In 2011 the discharge of springs varied from 0,1 to 275.6 L/s, however most of the measurements were classified within the V Meinzer's class (1–10 L/s) (Meinzer, 1923). The most efficient springs were located in the Szreniawa River basin (over 100 L/s) and the majority of them were of the fissure type, draining marl formations. The karst springs draining limestones formations were dominant in the Pradnik River basin and they showed lower rates of discharge (Table 2).

One of the most important results was that the spring discharge of the studied springs in 2011 was about 10–30% lower compared to the 1970s–1990s. 35 springs had completely vanished revealing the large impact on drawdown due to mining activity and deep-groundwater intakes. However, the low discharge of springs was also influenced by the exceptionally dry autumn season in 2011.

Table 2. Number of springs in discharge classes in the studied river basins based on the individual measurements in September 2011 (after Siwek, 2013)

River basin	Discharge			
	<1 L/s	1–10 L/s	10–100 L/s	>100 L/s
Dlubnia	11	7	6	
Nida	2	1	5	
Pilica	4	4	14	2
Pradnik	5	13		
Przemsza	6	7	10	
Rudawa	4	18	3	
Szreniawa	3	5	8	5
Warta	9	12	10	
Other small basins	6	4	1	
Total	50	71	57	7

Chemical composition of spring water

The total mineralization and the specific electrical conductivity of investigated springs ranged from 152 to 812 mg/L and from 0.211 to 0.915 mS/cm respectively. According to the Szczukariew-Priklonski's classification, most spring water belongs to the bi-ionic hydrochemical HCO_3 – Ca class, however, water of more complex chemical composition was also identified (Fig. 2). The highest total mineralization was recorded in the springs supplied by the Cretaceous aquifer

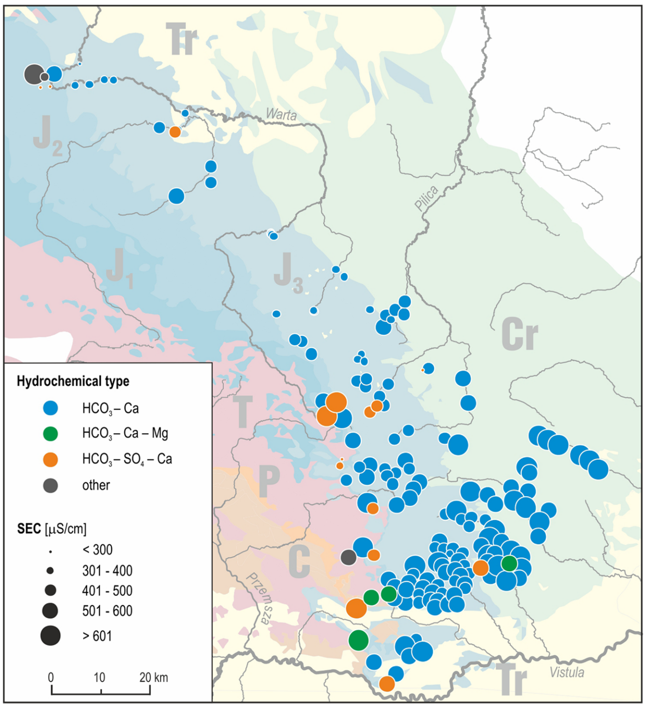

Figure 2. The hydrochemical types and Specific Electric Conductivity (SEC) of spring water in September 2011.

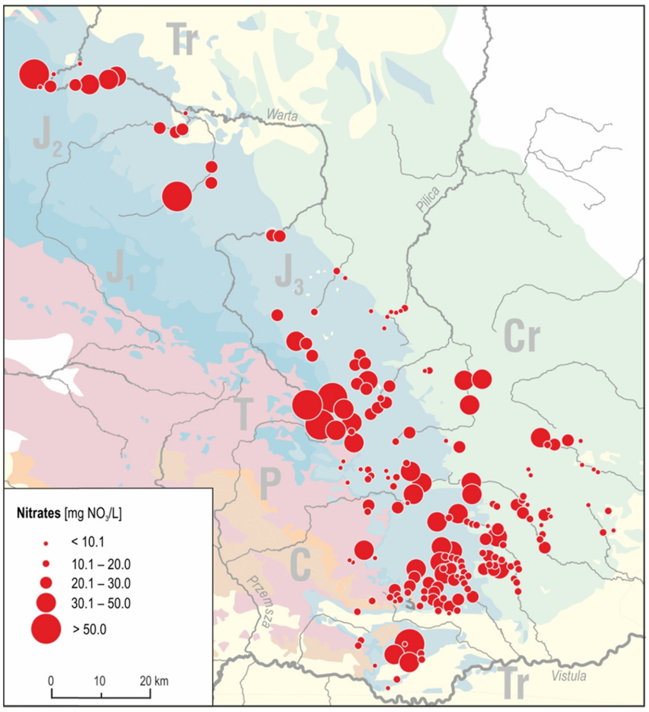

Figure 3. Nitrates concentrations in spring water in 2011.

(Szreniawa River basin). Springs draining the Jurassic aquifer (Pradnik river basin) showed the lowest values. The Mg^{2+} ion revealed the highest variability in water composition. The highest concentrations of this ion were found in the Szreniawa River basin and were formed by Cretaceous marls.

The chemical composition of water has been changing over the past 40 years. Apparently, the highest differences concern the Ca^{2+} ion. In 2011 its concentration was higher in all catchments (4–10%), with the highest differences in the basins of the Warta, Szreniawa and Dlubnia. On the other hand, an increase of approximately 30% of total mineralization was observed at the end of the 20th century in the Pradnik, Dlubnia and Szreniawa basins compared to the 1970s (Siwek and Chelmicki, 2004).

The spring-water contained only trace amounts of NH_4 and NO_2. As the oxygen amounts were reasonably high, the only form of nitrogen was $N\text{-}NO_3$. The nitrate concentration reached 112.7 mg NO_3/L, but in most cases ranged between 6–35 mg/L (Fig. 3). The phosphate concentration rarely exceeded 0.1 mg/L.

The hydrogeochemical background, defined as the range of ion concentration between the 10th and 90th percentile of the empirical distribution (Matschullat et al., 2000), had slightly changed in 2011 in comparison with 1999 and 2000 (Fig. 4). There were many differ-

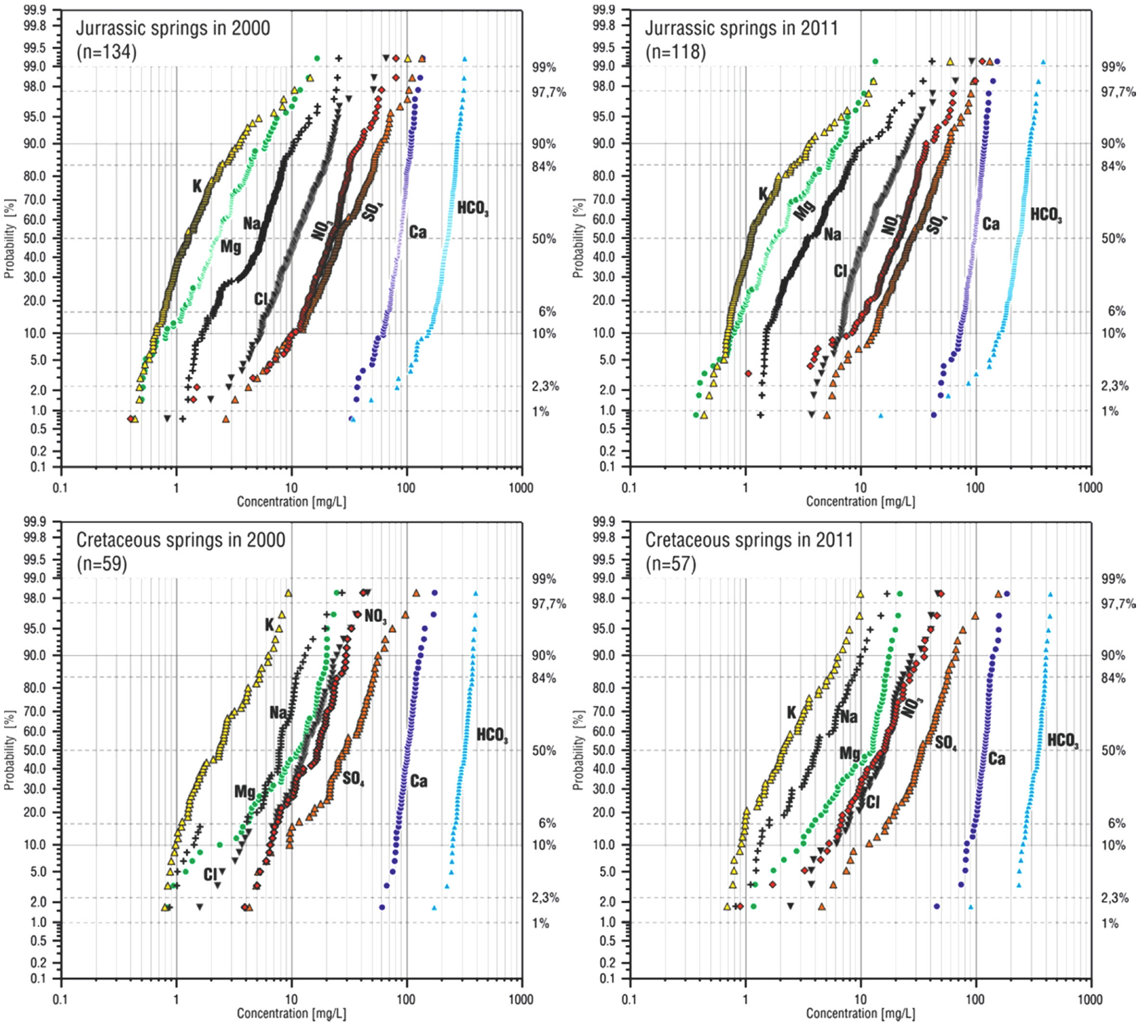

Figure 4. The hydrochemical background of spring water supplied by Jurassic and Cretaceous aquifers in 2000 and 2011 (after Rzonca, 2013).

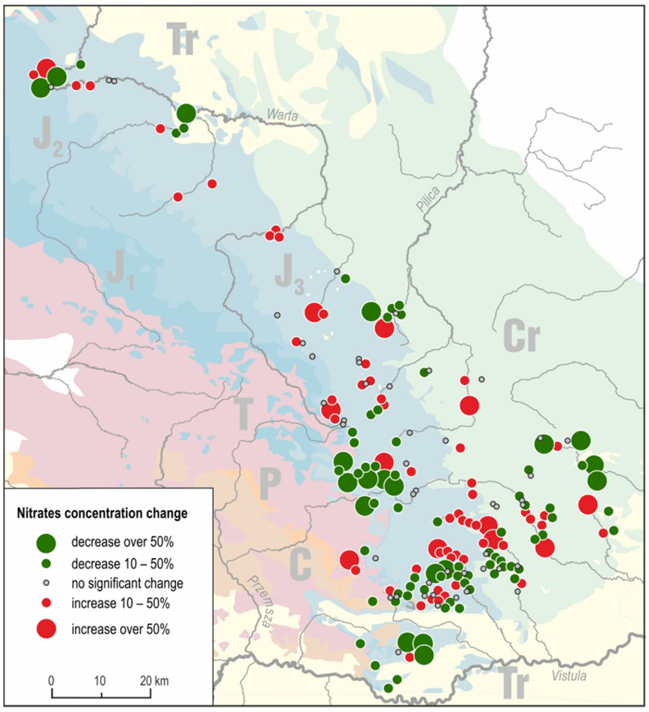

Figure 5. The difference in nitrates concentrations in spring water in 1999–2000 and 2011.

ences between the hydrogeochemical background concentrations for springs draining Cretaceous marl and Jurassic limestone aquifers between 1999–2000 and 2011.

In springs draining the Cretaceous aquifer, the most evident changes were observed for Ca^{2+} (from 81–127 to 89–138 mg/L), HCO_3^- (from 250–371 to 260–400 mg/L), SO_4^{2-} (from 9,6–55 to 13,0–63 mg/L) and Cl^- (3,9–23 to 6,3–27 mg/L). In case of NO_3^- ions – only a slight increase from 6,7–29 to 5,9–32 mg/L was noted. Concentrations of Mg^{2+} and Na^+ ions were reduced from 20 to 17 and from 13 to 10 mg/L respectively (Fig. 4).

In springs draining the Jurassic limestone aquifer, a substantial increase of Ca^{2+} concentration from 62–108 to 73–118 mg/L was found compared to 1999–2000. Only slight changes of concentration of HCO_3^- (from 154–271 to 165–291 mg/L) and Cl^- (from 5,4–22 to 6,8–25 mg/L) were noted. It is worth noting that there is a significant decrease in concentrations of both the NO_3^- and SO_4^{2-}. The hydrogeochemical background changed from 11–38 to 8,7–36 mg/L in case of NO_3^- and from 11–57 to 13–56 mg/L in case of SO_4^{2-}. On the other hand, a slight decrease in water quality was observed in the contact zone of Jurassic and Cretaceous strata in the Dlubnia river catchment (Fig. 5).

Ecological conditions

The biodiversity of fauna in springs depends on the flow conditions, water quality, quantity and speed of water flow, the material accumulated around the outflow, and the land use in the spring catchment. Bryophytes and herbaceous plants are the main vegetation in springs. A number of protected species are found around some of the investigated springs. The presence of non-native species, including invasive ones, shows progressive synanthropisation in some springs.

There are over 200 species of diatoms – including many rare species, which represent high ecological diversity values in the Krakowsko-Wielunska and Miechowska Uplands. One of the most important factors threatening the existence of many species of diatoms are the nitrates (Wojtal, 2013a). Lower concentrations of nitrate and other ions recorded in 2011, despite the widespread dominance of diatom species (β-mezosaprobic and mezo-eutrophic), indicated a high concentration of nutrients in some springs (Wojtal, 2013b). This favors the persistence of species tolerating inferior environmental conditions and eliminates pollution-sensitive diatoms. However, even springs located in rural or urban areas, are inhabited by rare and endangered species. Some springs act as refuges for species characteristic of the investigated uplands and as a retreat for species reflecting paleo environmental conditions. The species found in the springs represent different taxonomic groups i.e., *Sperchon squamosus, S. thienemanni, Lebertia stigmatifera, Oxus ekmani; Drusus trifidus, D. annulatus, Potamophylax nigricornis, Bythinella austriaca, Crenobia alpina, Hygrobates norvegicus; Gammarus fossarum, Cochlearia polonica*. Also, at least 214 species of diatoms were found representing the genera: *Nitzschia* (30), *Gomphonema* (20) and *Navicula* (16). Some of the species found are protected in Poland (i.e., *Nasturtium officinale, Cochlearia polonica, Eurhynchium striatum*). There were also some species in danger of extinction, included in Polish Red Data Book of Animals (i.e., *Bythinella zyvionteki*) or Polish Red Data Book of Plants *(Cochlearia polonica, Amphipleura pellucida Kützing, Caloneis fontinalis, C. lancettula (Grunow) Cleve-Euler, Cocconeis pseudothumensis Reichardt, Fragilariforma nitzschioides (Grunow) Williams & Round, Geissleria decussis (Østrup) Lange-Bertalot & Metzeltin, Gomphonema vibrio Ehrenberg, Navicula oligotraphenta Lange-Bertalot & Hofmann, N. striolata (Grunow) Lange-Bertalot, N. upsaliensis (Grunow) Peragallo, Pinnularia rupestris Hantzsch, P. viridiformis Krammer, Psammothidium lauenburgianum (Hustedt) Bukhtiyarova & Round, Sellaphora bacillum (Ehrenberg) D.G. Mann, S. hustedtii (Krasske) Lange-Bertalot & Werum, Stauroneis thermicola (Petersen) Lund, Surirella brebissonii Krammer & Lange-Bertalot i S. crumena Brébisson)* (Dumnicka, 2013; Wojtal, 2013a).

Threats to springs

Research carried out in 2011 revealed that both protected and non-protected springs in the Krakowsko-Wielunska and Miechowska Uplands are threatened by various impacts. Threats to the quality and quantity of spring waters can be classified into two different categories: natural and anthropogenic (Table 3). Natural threats are unavoidable and they lead to the natural evolution of spring ecosystems. The anthropogenic threats which may affect the investigated springs, occur in the spring recharge area, i.e., urban sprawl, growing demand for groundwater, coal mining activity, overexploitation of groundwater aquifers, agriculture activity (primarily cultivation), or landfill of hazardous waste in rural area. Among the main challenges for the investigated springs are, for example,increases in nutrients (fertilizers), reductions in discharge (or even decline of springs), degradation of landscape or loss of habitats.

Mapping of springs in the Krakowsko-Wielunska and Miechowska

Table. 3. Present threats to the springs in the Krakowsko-Wielunska and Miechowska Uplands

Category	Process	Examples of principal impacts
Natural	Flood	Filling of spring spaces with fluvial deposits Erosion of spring spaces
	Lack of precipitation	Decrease of groundwater table Change of location of springs Temporary or continuing decline of springs
	Excess rainfall	Slumping of unconsolidated sediments around spring vents
Anthropogenic	Development of residential area	Changes of surrounding space: re-profiling and levelling The removal of irreplaceable features of springs e.g., landform, vegetation, geological exposure Degradation of landscape and landforms Loss of spring spaces and outflows Connection to underground canalization system Waste disposal and landfill issues around spring vents
	Mining activity	Decrease of groundwater table Decline of springs
	Overexploitation of water	Depletion of groundwater resources
	Dredging of rivers	Decrease of groundwater table Change in location or decline of springs
	Agriculture	Increase of nutrient components in groundwater Pollution of water due to infiltration of plant protection products Changes in vegetation around springs in abandoned fields
	Long distance transport of industry air pollutions	Wet and dry deposition of pollutions, infiltration Changes in chemical composition of groundwater
	Landfill of hazardous waste in rural area	Changes in chemical composition of groundwater
	Tourism	Littering Soil compact Loss of vegetation cover
	Lack of public understanding	Inappropriate management causes destruction of natural features Emplacement of local landfills in spring outlets Damage to springs covers (graffiti, spray-painted masks etc.)

Uplands led to conclusion that water intake from springs may lead to irreversible changes of the environment. Outflow casings often have an unsightly appearance and need renewal. On the other hand, springs that are not used for water supply may become overgrown with vegetation, vandalised or even littered. Water and municipal management, such as river training and changes to roads, dams and bridges change may often lead to their disappearance or considerable transformation. Just 38% of investigated springs have not undergone physical changes, and 13% of springs had either dried up or are threatened by drying.

Conclusions

Springs are sometimes not a spectacular phenomenon (except for vaucluse springs) but they are always very important elements of the natural environment. There are several values which clarify the importance of springs both in geoconservation and preservation practices (Prosser, 2002). They have ecological, educational, aesthetic, sociocultural, touristic and recreational values. The biological (biotic) system of springs is inextricably connected to the physical system (abiotic), and together, they contribute to biodiversity. Sometimes springs are renowned as hotspots not only for biological but also for its cultural diversity, and the presence of endangered or unique species as well as the ethnological and historical factors that often greatly influence their management (Springer and Stevens, 2009). The analysis of physical and chemical properties of springs and the space around them helps to assess a transformation of the landscape and springs may be considered as important indicators of the environmental quality.

Research conducted in the South-Central Poland showed that springs in the Krakowsko-Wielunska and Miechowska Uplands are quite sensitive to human impact like most of karst springs in other karst regions (Tal and Katz, 2012). Water quality deterioration in the 20^{th} century is clearly visible in the central and northern border parts of the investigated area and it refers mainly to the content of nutrients, as is also seen in Florida and the Appalachian Region (Coxon, 2011; Albertin et al., 2012; Huebsch et al., 2014). On the other hand in the Prądnik River catchment (Ojcowski National Park) the decrease in the concentrations of ions indicates improvement of the environment quality. Understanding the functioning of ecosystems of springs, needs more research on their conservation and management, even if they are partly changed. Spring protection is crucial in maintaining the unique landscape of the Krakowsko-Wielunska and Miechowska Uplands. Protection of springs should be based on: rational management of natural resources. This should be carried out by close cooperation between local authorities and the owners of the spring areas. Environmental awareness, also needs to be developed in local communities and visitors (educational materials, brochures, etc.).

According to the ongoing economic, environmental, and legal requirements, related to the preservation and conservation of natural resources in European Union, it is very important to monitor springs. The identification of changes in springs and their surroundings requires interdisciplinary monitoring to identify possible threats. In order to protect geodiversity of spring ecosystems it is important to determine the limits of human activity in the headwaters of rivers. Further research should be focused on monitoring of yield and water temperatures of springs. The analysis of hydrograph recessions, rainfall time series and water temperature dynamics may give a direct reflection of many processes that occur within aquifer system as well as on the Upland's surface.

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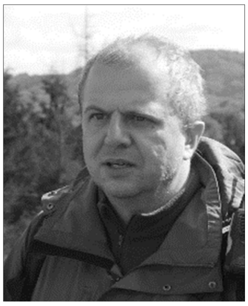

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