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ORIGINAL PAPER

IMPACT OF HYDROMETEOROLOGICAL CONDITIONS ON THE CHEMICAL COMPOSITION OF WATER IN CLOSED-BASIN KETTLE PONDS: A COMPARATIVE STUDY OF TWO POSTGLACIAL AREAS

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Abstract

Basins without outlets are natural storage reservoirs that can hold rainwater surpluses in a catchment for a time. In Poland, they have been an object of detailed fieldwork in the upper Parsęta and Potok Oliwski catchments, where they occupy a substantial proportion of the area. It was found that the prevailing weather conditions had a notable effect on the chemical composition of the surface water in the kettle ponds examined. The basic method of indoor work was an analysis of topographic maps and the statistical processing of the material collected. The fieldwork included a cycle of measurements in the hydrological years 2006 and 2007 and for 8 kettle ponds in the upper Potok Oliwski catchment. Hydrochemical mapping was carried out for 20 kettle ponds located in two subcatchments of the upper Parsęta catchment and for 8 kettle ponds in the upper Potok Oliwski catchment. Ion concentrations in surface water were determined with the help of analytic methods complying with the ISO and EPA standards. On the basis of the results obtained for those two geographically and hydrographically distinct catchments, great hydrochemical diversity was recorded, visible not only in a wide range of ion concentrations or such indices as specific electrolytic conductivity and pH, but also in the hydrogeochemical types found among the surface waters of individual basins. Because of their isolation from the horizontal inflow, the chief cause of the chemical differences in their waters is the vertical exchange.

Keywords: hydrometeorological conditions, absorptive and evapotranspiration basins without outlets, chemical composition, hydrogeochemical types.

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INTRODUCTION

The occurrence of closed basins has a substantial impact on the present-day character of the water cycle in a river basin since they create special circulation conditions and offer a natural possibility of rainwater retention (Brooks 2004). It is all the more important as Poland's water resources are modest when compared with other European countries (Kallis, Butler 2001) and the amount of water at our disposal largely depends on precipitation (Thakur et al. 2012). This implies the possibility of the retention of rainwater from built-up areas. We should not forget either that water resources will be reduced as a result of climate change (Vörösmarty et al. 2000, Christensen et al. 2004). Apart from studies of quantitative nature, it is also necessary to conduct qualitative research. The literature shows that there are many natural conditions (physical, biological, geographical, hydrological, meteorological) which affect the chemical status of water (Fujita et al. 2000, Hayashi et al. 2004, Said-Pullicino et al. 2007).

A special role in the hydrographic network is played by areas with no outlet. Chemical changes in the water of such areas should therefore be connected with vertical exchange, i.e. atmospheric precipitation and evaporation, and with horizontal exchange, or groundwater inflow and outflow (Sophocleous 2002). As a result, surface water's chemical composition should be close to that of rainwater or groundwater. According to LaBaught et al. (1997), in the catchments of lakes without outlets located in the northern and central parts of Minnesota, the contribution of groundwater alimentation is estimated at 74%. In turn, according to Brinson (1993), the atmospheric alimentation of ombrogenous wetlands located in areas without outlets contributes about 70%. Thus, as can be observed, those are areas differing in their hydrogenesis, although it is true that only two alimentation sources predominate here, i.e. atmospheric precipitation and groundwater inflow. However, there may be additional factors in the environment that will alter the physico-chemical composition of water and differentiate various areas from one another (Marr et al. 2000, Yan et al. 2002, Shomar et al. 2005, Lowenstein, Risacher 2009). Among those other conditions that can influence the quality of closed basins are their morphometric features, the hydrodynamics of processes occurring in a catchment, and routes of water inflow (Lischeid, Kalettka 2012). The remaining factors include the land-use pattern and agricultural pollution connected with it, primary production and the type of soil cover.

The chief goal of this paper is to determine the influence of hydrometeorological conditions on the chemical composition of water and hydrological conditions in closed basins. A more detailed goal is to establish possible differences between individual areas without outlets, even though they lie in the same postglacial zone. The geographical individuality of small landforms with no surface runoff can be characterised on the basis of their morphometric indices, lithology, soil distribution, and the physical and chemical properties of surface- and groundwater in their catchments. An attempt is also made to find other potential factors that can affect the quality of those bodies and their hydrochemical diversity.

Study area

Fieldwork was conducted in the catchments of the upper Parsęta and Potok Oliwski, rivers situated in the Baltic drainage area in the coastal zone of northern Poland. The upper Parsęta catchment (Figure 1) occupies an

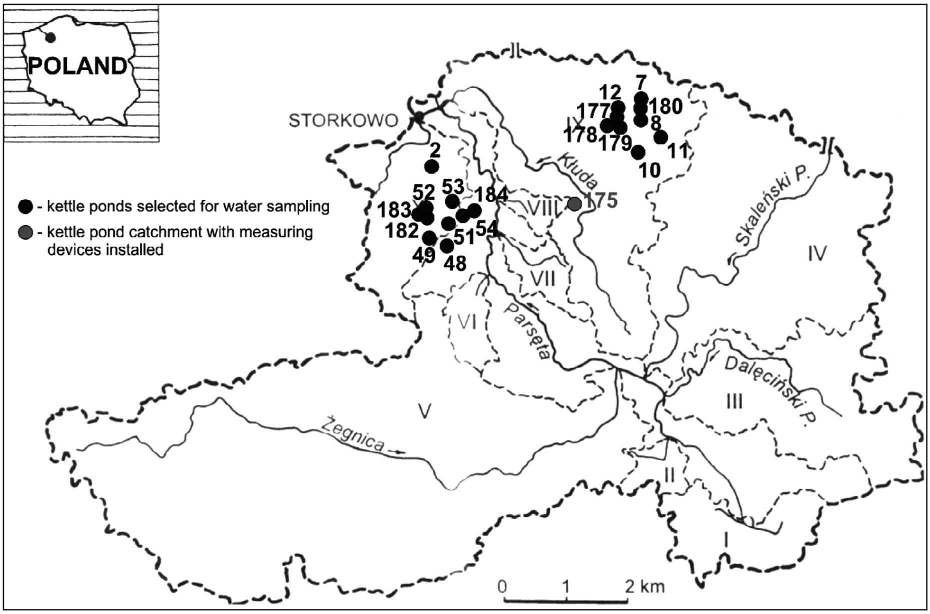

Fig. 1. Location of the upper Parsęta catchment with closed evapotranspiration basins selected for water sampling

area of 74.0 km^2, and the river has a length of 13.26 km. The catchment belongs to the agricultural-woodland type because of the prevalence of arable land and forests, which together occupy about 78% of its area. Woodland accounts for 34.6% of the catchment area, with the predominance of conifers (21.7%) and arable land (43.4%). In turn, meadows and pastures occupy 15.4%, mining areas, 2.4%, and the remaining 3.4% goes to built-up and transport areas (Piotrowska 1994).

There is abundance of depressions without outflows in the upper Parsęta catchment, where a total of 358 landforms with no surface runoff have been distinguished, which gives them a density of 4.84 per 1 km^2. Of this number 164 are absorptive basins, with a density of 2.22 per 1 km^2. Kettle ponds, in turn, are concave landforms filled with water, and they amount to 194, or 2.62 per 1 km^2.

The distinguished closed basins take up a substantial proportion of the area of the upper Parsęta catchment – 8.33 km², or 11.26%. More than half of it is occupied by infiltration basins – 4.26 km², or 5.76%, while kettle ponds account for 4.07 km², or 5.5%.

The upper part of the Potok Oliwski catchment occupies an area of 7.25 km². The principal streams of the catchment are the Potok Oliwski together with its tributaries (Figure 2). The greatest part of this area, 2.71 km², is

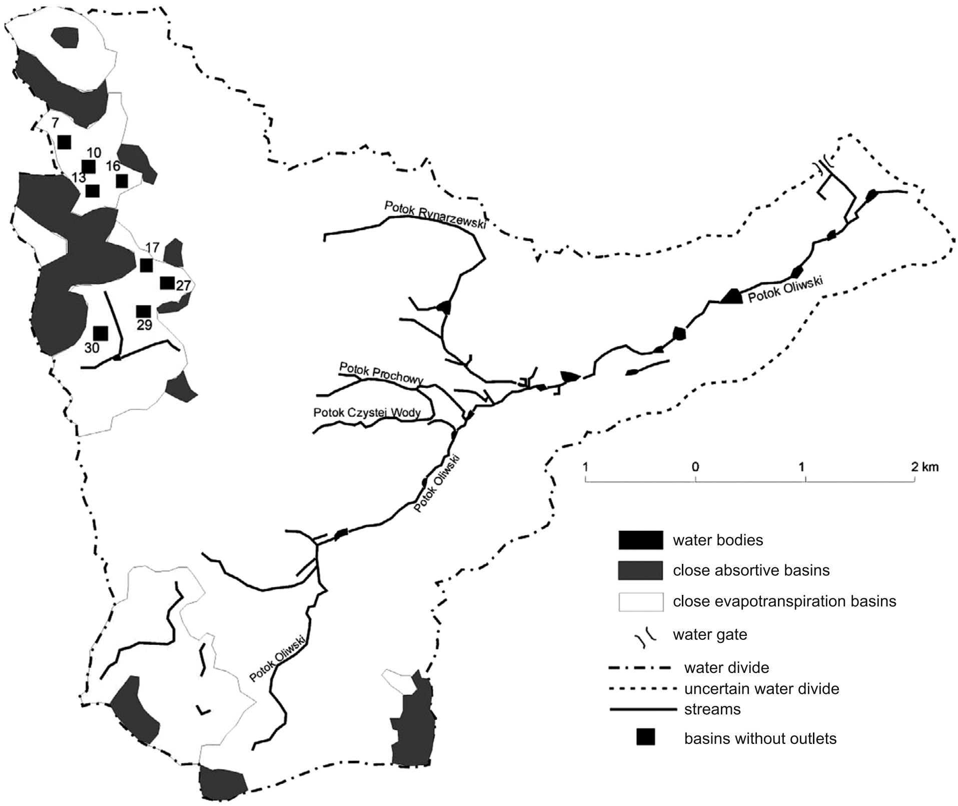

Fig. 2. Location of the Potok Oliwski catchment with closed evapotranspiration basins selected for water sampling and location of basins without outlets in the upland part of the Potok Oliwski

covered by woodland. Farmland comes second, at 2.03 km². The next use is building, mostly housing estates as well as industrial facilities and large-lot shopping centres, occupying a total of 1.45 km². A highly characteristic feature of land development in the catchment of the stream is the Tri-City ring road running north-south. It is also a sort of boundary in the land-use pattern, despite small distances, dividing the upland into a poorly afforested and dynamically overbuilt western part and a forest-covered eastern one.

The absence of organised surface runoff and the postglacial geological structure of the substratum give rise to two types of closed basins: infiltration and kettle holes. There are eight closed evapotranspiration basins in the catchment (Figure 2). Their depth (or the topographic distance from the border to the bottom of a basin) does not exceed 1.25 m, while the biggest one has an area of more than 12,000 m^2 and a volume of 4,100 m^3. Most of the depressions have an area of several hundred square metres and a similar volume.

METHODS

The documentary material employed was composed of topographic base maps at a scale of 1:10,000, and in the case of the Potok Oliwski, hydrographic maps at a scale of 1:50,000 (the sheets 3449D Gdańsk-Osowa and 3450C Gdańsk). The basic method of work was an analysis of the topographic maps and the statistical processing of the material collected. The fieldwork included a cycle of measurements in the hydrological years 2006 and 2007.

The meteorological conditions during the measuring period were identified on the basis of the results of studies carried out at the AMU Geoecological Station in Storkowo and a measuring station near the Gdańsk Refinery. It was a continuous record by a MILOS 500 automatic station. Meteorological monitoring embraced measurements of air temperature and the amount and distribution of precipitation.

On the basis of detailed cartographic analyses and a field survey, six catchments of closed evapotranspiration basins were selected for stationary research: „Przeradź", „Sławno", „Krągłe" (located in the lakeland elevation zone), as well as „Sadkowo", „Gruszewo" and „Rogowo" (within the 6th, 5th and 4th upland levels, respectively) with permanent or temporary kettle ponds in their bottoms. All those catchments had a similar, mid-field type of location.

Hydrochemical mapping was carried out for 20 kettle ponds located in two subcatchments of the upper Parsęta catchment (the Kłuda catchment – ten kettle ponds numbered 7, 8, 10, 11, 12, 177, 178, 179, 180, and 181, and the Młyński Potok catchment – ten kettle ponds numbered 2, 48, 49, 50, 51, 52, 53, 54, 182, and 183), and for 8 kettle ponds in the upper Potok Oliwski catchment (Figure 2). One of such basins in the upper Parsęta catchment, characteristic of the postglacial zone, was chosen for a detailed field study, and its catchment was equipped with instruments for this purpose. This is the topographic (2nd order) catchment of a closed evapotranspiration basin 3.5 ha in area, which is 105 m long, 90 m wide and 5.9 m deep. Situated in its bottom is a mid-field kettle pond (no. 175). In the Potok Oliwski catchment, in turn, a detailed study was made of basin no. 27. This was dictated by its location in the lower part of the marginal zone of the catchment, on the transit route of water flowing from the Gdańsk Upland. It also had morphometric parameters typical of the majority of closed basins in this catchment. It was 80 m long, 50 m wide, and 2.5 m deep.

Surface water from permanent or temporary kettle ponds was sampled four times a year in weather seasons if there was water in their basins.

When sampling was impossible, e.g. due to low air temperatures and the freezing of the ponds, it was performed a month later.

Ion concentrations in surface water were determined with the help of analytic methods complying with the ISO and EPA standards (Coquery et al., 2005). The hydrogeochemical types of water were determined using the Shchukariev's method on the basis of the level of seven basic ions: Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{2-}, and Cl^{-}, and three additional, NH_4^{+}, NO_3^{-} and PO_4^{3-}, if their content in water exceeded 20% meq [mval] of the anion or cation total (Chadha, 1989).

RESULTS AND DISCUSSION

Hydrometeorological conditions

The years when the research was conducted in the upper Parsęta and Potok Oliwski catchment differed in terms of temperature and precipitation (Figures 3, 4). They can be classified as follows:

– the year 2006 was normal in thermal terms and dry in terms of precipitation: the mean temperature was 7.7°C (Parsęta) and 7.6°C (Potok Oliwski) and the annual rainfall, 603.9 mm (Parsęta) and 544.6 mm (Potok Oliwski);

– while the year 2007 was distinctly different: it was warm with a mean air temperature of 9.4°C (Parsęta) and 9.2°C (Potok Oliwski), and wet with an annual rainfall of 855.2 mm and 701.4 mm (Potok Oliwski).

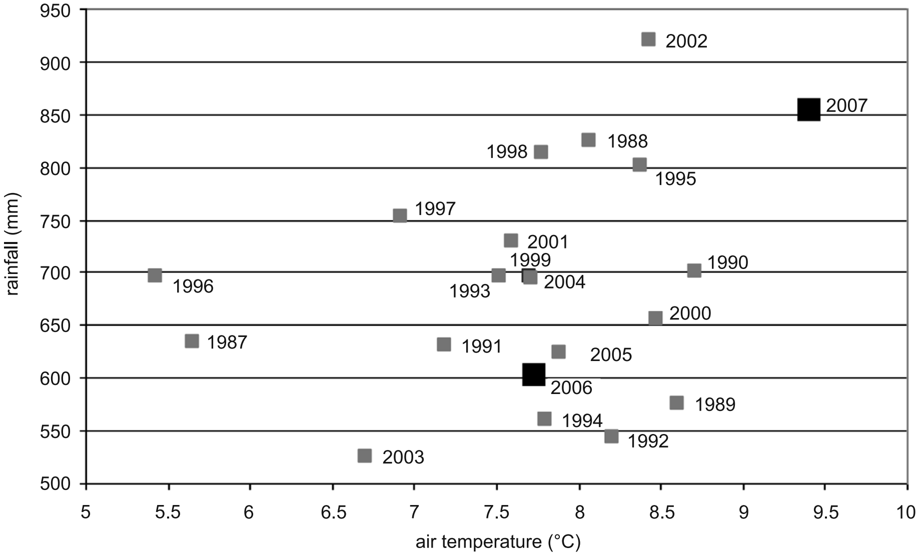

Fig. 3. Thermal and precipitation conditions at Storkowo in the hydrological years 2006-2007 as compared with the multi-year period 1987-2005

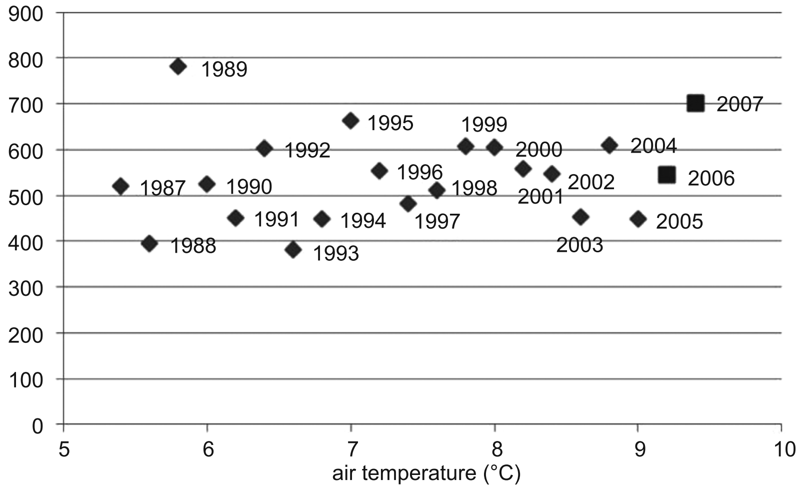

Fig. 4. Precipitation conditions (mm) in Gdańsk in the hydrological years 2006-2007 as compared with the multi-year period 1987-2005

The differences in the thermal and rainfall conditions between the two years were reflected in variations in the levels of surface- and groundwater in the kettle-pond catchments, as well as in the loads of solutes reaching the geoecosystems of those catchments.

As stated above, the two years differed considerably in terms of temperature and precipitation (Major 2012). The range of the mean annual temperature amounted to 1.7°C at Storkowo and 1.6°C in Gdańsk (Table 1). Usually, the warmest month of the year is July. It was so also in July 2006, when the highest mean monthly temperature of 21.1°C was recorded in Storkowo and 20.8°C in Gdańsk. A year later, in the three summer months of June, July and August, the temperature stayed at 16°C or slightly higher at both measurement stations (Table 1).

Table 1

Mean monthly air temperatures in the upper Parsęta and the upper Potok Oliwski catchments in the hydrological years 2006-2007

Hydrological year (months)	11	12	01	02	03	04	05	06	07	08	09	10	Mean
Storkowo													
2006	3.1	0.0	-6.5	-1.6	-1.0	6.9	12.2	16.3	21.1	16.3	14.8	10.3	7.7
2007	6.4	4.9	3.5	-0.2	5.6	8.4	13.7	17.5	17.0	17.1	12.0	6.4	9.4
Gdańsk													
2006	3.6	0.8	-5.5	-0.5	-1.3	5.5	10.3	15.4	20.8	15.9	15.2	10.5	7.6
2007	6.8	5.3	4.0	0.3	5.3	7.4	11.6	16.6	16.7	16.6	12.4	6.9	9.2

In the two years, the lowest mean monthly temperatures were recorded in various months. In 2006, at the Storkowo station the coldest one proved to be January with a mean monthly temperature of -6.5°C. Two other months had sub-zero mean temperatures: February (-1.6°C) and March 2006 (-1.0°C). In 2007, it was only in February that the mean monthly temperature fell below zero, down to -0.2°C (Table 1). A similar situation was at the Gdańsk station. In 2006, the coldest month proved to be January with a mean monthly temperature of -5.5°C. There were two other months with sub-zero mean temperatures: February (-0.5°C) and March 2006 (-1.3°C). In 2007, there was no month with sub-zero temperature (Table 1).

As shown by the research carried out at all the Base Stations of Integrated Monitoring of the Natural Environment in Poland in connection with obligatory IMNE measuring programmes, in the hydrological years 2006 and 2007 precipitation in the summer half-year exceeded that in the winter, the proportion being roughly 60% : 40% (Major 2009).

As in the case of thermal conditions, the two years under study differed substantially in terms of precipitation (Major 2012); both also departed from the multi-year mean (670.6 mm) calculated for the decades 1963-1982 at the Szczecinek station (West Pomerania – 18 km from Storkowo). The year 2006 was dry, and 2007 was wet (Table 2).

Table 2

Monthly rainfall in the upper Parsęta and the upper Potok Oliwski catchments in the hydrological years 2006-2007

Hydro-logical year (months)	11	12	01	02	03	04	05	06	07	08	09	10	Total
Storkowo													
2006	36.3	115.4	9.6	27.1	32.1	29.1	73.2	38.3	22.9	154.0	44.2	21.7	603.9
2007	66.0	45.3	139.8	38.5	36.0	21.3	98.2	132.9	134.8	45.5	79.3	17.6	855.2
Gdańsk													
2006	37.1	18.1	13.0	36.0	33.0	32.2	16.4	71.1	110.9	149.1	28.3	44.8	590.6
2007	55.1	33.6	18.3	42.1	35.0	30.1	29.7	98.2	123.7	108.5	57.9	29.9	662.1

The highest monthly rainfall totals at Storkowo and Gdańsk reached 154.0 mm and 149.1 mm, respectively, and occurred in August 2006. The precipitation recorded at Storkowo exceeded 100 mm three more times over the study period, with 139.8 mm in January, 132.9 mm in June, and 134.8 mm in July 2007 (Table 2). The precipitation measured at the Gdańsk station also exceeded 100 mm three more times, with 110.9 mm in July 2006, 123.7 mm in July 2007, and 108.5 mm in August 2007 (Table 2).

The lowest monthly rainfall total at Storkowo, a mere 9.6 mm, was recorded in January 2006. There was just one more time that precipitation was less than 20 mm, in October 2007, when it was equal to 17.6 mm (Table 2). The lowest monthly rainfall total in Gdańsk, a mere 13.0 mm, was recorded in January 2006. In three more months, precipitation was less than 20 mm: in December 2006, when it was equal to 18.1 mm, in May 2006, at 16.4 mm, and in January 2007, at 18.3 mm (Table 2).

Some large diurnal variations in the precipitation measured should not be ignored. Such events are not only of hydrological (Johnson et al. 2004), but also of geomorphological significance, because heavy precipitation can mould (transform) slopes in the catchments of closed basins.

Physico-chemical properties of surface water

Generally, surface water in the upper Parsęta catchment has pH of 6.5 to 8.5, and only rarely does this range extend from 4 to 9. The water flowing from marshes and forests is usually acidic because of the presence of humic and fulvic acids (Güler et al. 2002).

In five basins without outlets studied in the Kłuda subcatchment (numbered 10, 177, 178, 179 and 180), the reaction of surface water was usually close to neutral and ranged between pH 6.5 and 8.5. In only one kettle pond, no. 7, water had pH higher than 9 (alkaline reaction), which could be due to the discharge of waste from an agricultural holding adjacent to its catchment. The remaining kettle ponds in this catchment had acidic or weakly acidic reaction, which showed the greater effect of alimentation by precipitation. The pH values in the surface waters of the examined basins ranged from 4.2 to 10.1.

In the Młyński Potok subcatchment, water had weakly acidic reaction, which is indicative of the alimentation of the kettle ponds there by precipitation. It was only in pond no. 53 that water had acidic reaction, which it usually acquires from humic acids that form in the process of the decay of organic substances (Chiou et al. 1987). In kettle pond no. 183, in turn, water was weakly alkaline; it must have circulated in glacial deposits and their weathered residue, which are richer in $CaCO_3$ (Major 2012). The range of variation of the pH there was from 4.1 to 7.4.

In the closed basins of the Potok Oliwski catchment, water was usually weakly acidic and neutral, indicating alimentation by precipitation. Here the pH values ranged from 5.5 to 8.5. This is probably due to the human impact, including the effect of the Tri-City ring road.

Specific electrolytic conductivity (SEC) is an index showing the level of chemical compounds dissolved in the surface waters of the kettle ponds. A similar parameter is the concentration of ions that determine the level of conductivity (Gordeev, Sidorov 1993, Kostrzewski et al. 1994).

When analysing the research results, one can note important spatial differences in specific electrolytic conductivity (Major 2012). In the Kłuda subcatchment, SEC variability ranged from 15.7 to 805 μS cm^{-1}, while in the Młyński Potok subcatchment it varied from 32.4 to 352 μS cm^{-1}, and in the

Potok Oliwski catchment – from 80.0 to 221 μS cm^{-1}. Low conductivity figures are indicative of a major predominance of the precipitation type of alimentation of the kettle ponds, while the very high SEC values in pond no. 10 in the Kłuda subcatchment were probably due to the discharge of waste from a nearby agricultural holding.

On the basis of the ion concentrations, ionic balance sheets were prepared and the chemical composition of water (in per cent) was calculated (Figure 5).

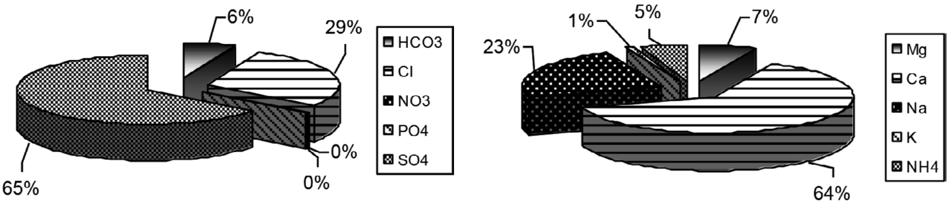

Fig. 5. Chemical composition (%) of surface water in the closed evapotranspiration basin under study (no. 175)

In the Kłuda catchment, there are usually simple, two- or three-component types of water:

– HCO_3^- - SO_4^{2-} - Ca^{2+}: the catchments of basins nos. 7, 11, 12, 177 and 179;

– HCO_3^- - Ca^{2+}: the catchments of basins nos. 8 and 178; and

– SO_4^{2-} - Ca^{2+}: the catchments of basins nos. 10 and 180.

In one closed evapotranspiration basin ("Przeradź", Table 3), in which measurements were conducted at various stages of the matter cycle, surface water was of a four-component hydrogeochemical type: SO_4^{2-} - Cl^- - Ca^{2+} - Na^+. In the contact zone of rainwater with the land surface, mineralisation grows several times. Rainwater is enriched with chemical compounds that boost its conductivity. No small role in the increase in surface water mineralisation is also played by the wash-out of chemical compounds from surface deposits and the alimentation of kettle-pond water by groundwater characterised by elevated mineralisation levels.

Table 3

An example of mean physico-chemical parameters of surface water in a closed evapotranspiration basin ("Przeradź") in the Parsęta catchment

Site	pH	SEC	HCO^-	$SO4_2^-$	Cl^-	NO_3^-	PO_4^{3-}	Ca^{2+}	Mg^{2+}	Na^+	K^+	NH_4^+	SiO_2
	(-)	(μS cm^{-1})	(mg dm^{-3})										
Closed basin "Przeradź"	4.6	279.5	12.2	96.0	31.3	0.3	0.4	30.4	1.9	12.9	1.1	2.3	19.7

In turn, there are three- and four-component types of water with longer sequences in the Młyński Potok subcatchment. The hydrogeochemical types, according to the Shchukarie's classification of natural waters (Kannel et al. 2007), look as follows:

– SO_4^{2-} - HCO_3^- - Ca^{2+}: basins nos. 51, 182 and 183;
– HCO_3^- - SO_4^{2-} - Ca^{2+}: basin nos. 48 and 52;
– HCO_3^- - SO_4^{2-} - Ca^{2+} - Mg^{2+}: basin no. 49;
– SO_4^{2-} - Cl^- - K^+ - Mg^{2+}: basin no. 53;
– HCO_3^- - Cl^- - K^+ - Ca^{2+}: basin no. 54; and
– HCO_3^- - Ca^{2+} - NH_4^+: basin no. 2.

After statistical analysis, the values were standardised and all the kettle ponds were grouped using the Ward's method. This resulted in their division into three groups, one group consisting of two subgroups (Figure 6).

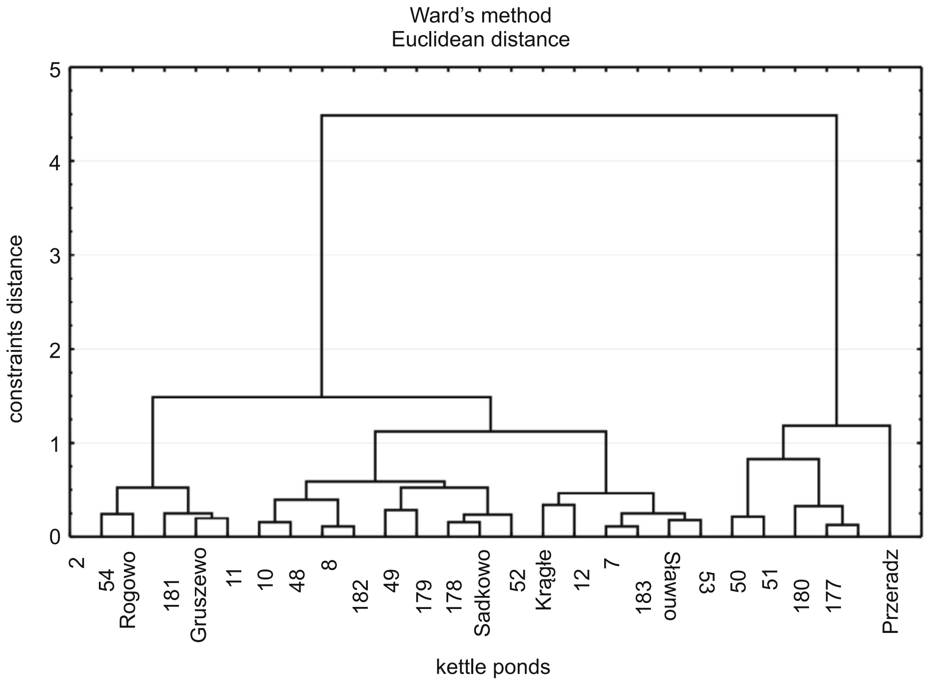

Fig. 6. Grouping of the mapped kettle ponds in the upper Parsęta catchment by their chemical composition using the Ward's method

The distinguishing feature of the first group was the lowest concentrations of sulphates. The second group contained two subgroups: the first (and the largest) was characterised by the highest concentrations of nitrates, while the second had the highest values of electrolytic conductivity. Another feature of all the kettle ponds from the second group differentiating them from the first and third groups was a high concentration of bicarbonate ions and magnesium. The third group had the highest concentrations of sulphates and ammonia ions.

In the Potok Oliwski catchment, in turn, the following ionic sequences were recorded:

– HCO_3^- - Ca^{2+} - SO_4^{2-}: 2 basins, nos. 16 and 27;
– HCO_3^- - Ca^{2+}: 3 basins, nos. 7, 17 and 30;
– SO_4^{2-} - HCO_3^- - Ca^{2+}: 1 basin, no. 29;
– HCO_3^- - Na^+ - Ca^{2+} - Cl^- - Mg^{2+} - SO_4^{2-}: 1 basin, no. 13; and
– Ca^{2+} - HCO_3^- - Na^+ - Cl^- - SO_4^{2-} - Mg^{2+}: 1 basin, no. 10.

As can be seen, two rare cases of a six-ion type of water could be observed. Examples of mean physico-chemical parameters of surface water in the closed evapotranspiration basins are shown in Table 4. The example selected is the qualitative composition of water in a closed evapotranspiration basin no. 27. The choice was dictated by the representative character of this basin not only in terms of location and environmental functions, but also the physico-chemical results obtained.

Table 4

An example of mean physico-chemical parameters of surface water in a closed evapotranspiration basin (no. 27) in the Potok Oliwski catchment

Site	pH	SEC	HCO^-	$SO4_2^-$	Cl^-	NO_3^-	PO_4^{3-}	Ca^{2+}	Mg^{2+}	Na^+	K^+	NH_4^+	SiO_2
	(-)	(μS cm^{-1})	(mg dm^{-3})										
Closed basin 27	6.0	255.0	88.9	46.0	12.0	0.4	0.2	35.5	3.0	11.0	0.8	1.3	15.0

As in the case of the Parsęta, also the Potok Oliwski closed basins were grouped according to their hydrochemical status using the Ward's method (Figure 7). Again, three groups were obtained, the third being divided into

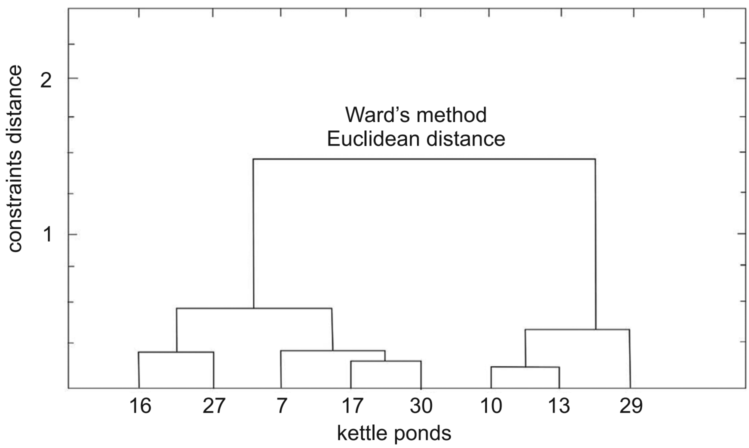

Fig. 7. Grouping of the mapped kettle ponds in the Potok Oliwski catchment by their chemical composition using Ward's method

two subgroups. The first group showed the predominance of bicarbonates and calcium, and a substantial proportion of sulphates; group two demonstrated the predominance of two ions: bicarbonates and calcium. The third group included basins with six-ion water (2 basins) and water with a substantial proportions of sulphates, bicarbonates and calcium.

The results obtained in the Potok Oliwski catchment (also during other sampling operations and from urbanised areas) clearly show a marked dependence between surface retention and precipitation figures over the same time interval (Figure 8). The immediate response to precipitation events and a great similarity of the lines representing the two elements are also characteristic.

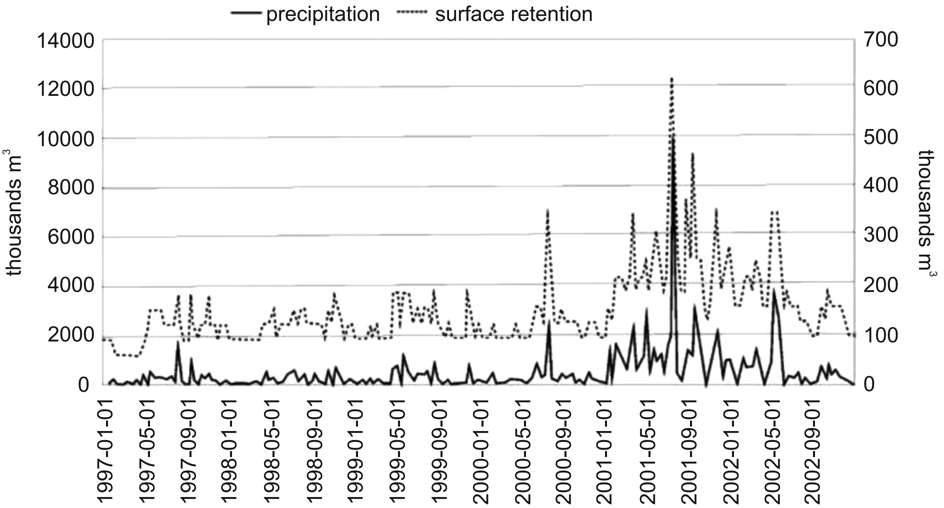

Fig. 8. Precipitation and surface retention in the Potok Oliwski catchment

The prevailing meteorological and hydrological conditions affected the physico-chemical properties of surface water in the closed evapotranspiration basins studied (Hidalgo, Cruz-Sanjulian 2001).

The character and location of closed basins in river catchments control the quality of water appearing in them. Since those bodies have no surface contact with the entire river system, their water quality depends primarily on the vertical exchange, and especially on atmospheric precipitation (Slobel et al. 2003). This is corroborated not only by ionic sequences, but also, or rather first of all, by concentrations obtained for individual chemical compounds that can be regarded as low and in many cases comparable with those in rainwater. On the one hand, what is significant is the hydrochemical aspect, or the quality of precipitation itself connected with the concentrations of basic ions and chemical compounds reaching the water. The other important aspects are geomorphological, or the intensity of precipitation and its contribution to the transformation of slopes in the catchments of the closed basins, and hydrological, or the amount of water that a precipitation event supplies to a basin. This is an important aspect because both analysed catchments have high precipitation figures: over the study period they ranged from about 600 mm to over 850 mm a year. In the case of torrential rains, closed basins are very often incapable of retaining the whole of the rainwater, therefore the water ‘escapes’ from a depression, in this postglacial area largely *via* underground flow (Chernet et al. 2001), partially to return later with overland flow, which can change the quality of rainwater considerably. The chief factors controlling the chemical composition of precipitation are meteorological conditions and air pollution (Kryza et al. 2012). They determine the amount of solutes supplied to the studied geoecosystems. Water coming straight from the atmosphere usually has acidic reaction and low mineralisation. And such were the values obtained for both streams. For the Parsęta, the minimum pH figure was 4, and in the case of the Potok Oliwski, about 5.5. Total mineralisation was also low, as manifested by low electrolytic conductivity values. They ranged from 80 to 221 μS cm^{-1} for the Potok Oliwski waters and from about 15 to 332 μS cm^{-1} for the Parsęta waters. It was only in specific situations that the Parsęta figure soared to about 800 μS cm^{-1}. For example, when precipitation passes through tree canopies, it undergoes not only qualitative but also quantitative changes: there is a change in the amount of water and the time it takes to reach the substratum. After such a passage, rainwater is enriched with chemical compounds that often boost its conductivity several times, to transform its properties again on contact with the land surface by leaching pollutants (Miao et al. 2011). In the case of the two streams, there were no such drastic changes, although there were situations when the concentrations of some indicator ions were elevated. The reason of such small increases is a negligible human impact. There is usually a rise in the levels of biogenic, organic and mineral substances as well as chemical compounds. In the two streams, there were measurable amounts of nitrates and phosphates, on average 0.2-0.3 mg dm^{-3} of phosphates and about 0.3-0.4 mg dm^{-3} of nitrates. Among biogenic substances, the highest levels were recorded for ammonia: from 1.3 to 2.3 mg dm^{-3}, depending on the stream. Especially dangerous are flows from urbanised areas and those transformed by man. Overland flow is then rapid while water pollution increases. The question of evaporation should not be neglected. In summer, rapid evaporation from a free water surface can lead not only to a decrease in the amount of water, and thus to a greater concentration of solutions and a change in its physico-chemical properties, but also to such developments as eutrophication or overgrowing with plants.

The identification of all those elements is necessary to gain an insight into the current status of the geoecosystems of closed basins and to facilitate the determination of the supply of atmospheric pollution, environmental development tendencies, possible threats, and ways of protecting depressions without outlets and their catchments as valuable elements of the natural environment.

Basins without outlets are elements of the hydrographic network highly significant for human management. They perform many functions, the most important being hydrological, ecological, geomorphological and economic ones

(Wenchao et al. 2010). They are chiefly potential natural retention reservoirs (a hydrological function) that can be used to offset the increasingly frequent deficits of water resources. In effect, they can receive substantial quantities of precipitation that are otherwise irretrievably lost, especially during torrential rain events.

CONCLUSIONS

At the time of the growing deficit of surface waters suitable for economic purposes, new solutions should be sought that offer the possibility of an increase in the water resources available to man. One of them is to take advantage of closed evapotranspiration basins that are a permanent element of the landscape, especially in northern Poland. However, one of the problems with their use can be the chemical composition of their water which, in turn, follows very often from the prevailing weather conditions. Annual rainfall totals in the two catchments under analysis ranged from 544.6 mm to 855.2 mm, and the rainwater affected the chemical composition of surface water. On the basis of the results obtained for those two geographically and hydrographically distinct catchments, a great hydrochemical diversity was recorded, visible not only in a wide range of ion concentrations or such indices as specific electrolytic conductivity and pH, but also in the hydrogeochemical types of surface water found in the individual basins. Surface water in the upper Parsęta catchment had pH of 6.5 to 8.5, only rarely extending from 4 to 9, its range in the Potok Oliwski catchment being from 5.5 to 8.5. With respect to another important indicator, that is specific electrolytic conductivity (SEC), the figures ranged widely from 15.7 to 805 µS cm^{-1} for water in the upper Parsęta catchment and from 80 to 221 µS cm^{-1} for that in the Potok Oliwski catchment. Because of their isolation from a horizontal inflow, the chief cause of the chemical differences in their waters is the vertical exchange (precipitation, evaporation, and groundwater inflow and outflow). In the contact zone of rainwater with the land surface, mineralisation grows several times, the rainwater being enriched with chemical compounds that boost its conductivity. Other processes stimulating the mineralisation of surface water are the leaching of chemical compounds from surface deposits and the alimentation of kettle-pond water by groundwater with an elevated mineralisation level. This is the situation we mainly observe in the upper Parsęta catchment. In the case of the Potok Oliwski catchment, the chemical composition of its surface water can also be greatly affected by human activity, including the effect of the Tri-City ring road.

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