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ORIGINAL PAPER

EFFECT OF A SMALL RETENTION SYSTEM ON THE TEMPERATURE AND CHEMISTRY OF A MID-FOREST HEADWATER STREAM*

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Abstract

This study on the effect of a small retention system on the temperature and chemistry of a mid-forest headwater stream has been conducted in the valley of the Kamienna Stream in northern Poland. The catchment of the stream is composed of glacial and fluvioglacial sandy deposits, which are deeply dissected by the stream valley. The catchment is covered mainly by forests with the predominance of beech, pine and spruce on the plateau and alder in the valley bottom. Small retention objects were built in 2007 and include a cascade of a few dammed shallow lakes of varied area. The stream's water was sampled at 8 stations distributed along the stream. The sampling took place at monthly intervals in 2013-2014. The temperature, pH and conductivity were determined *on situ*. The content of major cations and anions was analysed using an ion chromatography technique. The results showed only a limited effect of the small retention system on the water parameters studied. The warming effect of the dammed lakes was visible, although it disappeared at a short distance from the stream's flow out of the lake. The stream's flow through the retention objects resulted in a considerable increase of the Na^+ content and a slight decrease in the content of SO_4^{2-} and dissolved O_2. Conductivity and the content of Ca^{2+} and HCO_3^- showed an increasing tendency down the stream and no effect of the retention system was visible. Concentrations of the remaining water ionic components did not adhere to any distinct tendency. Water presented the calcium-bicarbonate character at every sampling point and over the whole study period.

Keywords: headwater ecosystems, small retention systems, water chemistry, riparian forests, human impact.

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INTRODUCTION

Water flow dynamics and chemistry in riverine systems are conditioned by many natural and anthropogenic factors. The geological structure of a catchment, relief and soil physical characteristics play are pivotal among natural factors (Frissell et al. 1986. Doyle et al. 2003). They determine the mechanisms and intensity of water flow through the catchment. Mineralogy and chemistry of rocks, sediments and soils and processes of their weathering determine water saturation with various substances (Maciaszczyk 1998, Mazurek 2008, Szostakiewicz-Hołownia 2012). Its flow through the catchment causes many geomorphic and ecological effects and strongly influence biota. Water bodies are integral and highly important components of river valley ecosystems, constituting hotspots in matter and energy flow and environments of various processes (Poff, Zimmerman 2010, Cheng, Basu 2017). Multidirectional interactions between abiotic and biotic components in river catchment geoecosystems, especially valley bottoms, constitute an important link in the global cycling of some substances, in particular biogenic elements (Alexander et al. 2000, Bonada et al. 2007). They have been a subject of many studies (e.g., Hupp 1992, D'Angelo et al. 1997, Obolewski et al. 2016).

Over the last millennia, the increasing impact of human activity, including deforestation, development of agriculture and settlement, mining and processing of natural resources, have strongly modified the structural and functional parameters of river catchments, in particular their valleys. Disturbances in water circulation and retention are subsequent effects of these activities (Buda, DeWalle 2009, Hasenmueller et al. 2016). Results of the studies of Kortelainen (1997) proved that significant disturbances can be caused even by seemingly minor environmental changes, such as the tree species composition in forests, which constitute an important stabilizing component of terrestrial landscapes (Tyszka 1995). The creation of small retention systems corresponds to significant interference in river valley ecosystems, which can have a number of ultimate effects, not necessarily positive ones (Radczuk, Olearczyk 2002, Mioduszewski 2004). Therefore, expanding such systems to a larger scale requires comprehensive, multidirectional studies, which will provide information on their potential impact on the entire river valley ecosystem. It is especially important for headwater river valleys, as they are highly sensitive ecosystems (Capon et al 2013).

Our study aimed to evaluate the effects of a small retention system on the temperature and water chemistry of a mid-forest headwater stream. Water samples were collected at monthly intervals over a 2-year-long observation period.

MATERIAL AND METHODS

Research area

The study was carried out in the valley of the Kamienna Stream, a left-bank tributary of the Słupia River (northern Poland). The stream catchment comprises a hilly landscape developed on the foreland of a disappearing ice-sheet of the Gardno Phase, Vistula Glaciation, whose age was estimated at 14500-14300 years BP (ROTNICKI, BORÓWKA 1994). Surficial deposits of the catchment constitute glacial and fluvioglacial sands with small patches of glaciolacustrine sediments. The stream valley is deeply incised into these deposits and its bottom is covered with fluvial sands and biogenic deposits (peat) in spring niches. Nowadays, almost the entire area of the catchment is covered with forests. Beech, pine and spruce predominate on the plateau, whereas black alder occurs in the valley bottom. The average annual temperature for last few decades has been around 7.6°C and the sum of precipitations is 770 mm (KIRSCHENSTEIN, BARANOWSKI 2008).

A small lowland retention project to be developed in the valley of the Kamienna Stream was started in 2007. The designed retention objects include a cascade of dammed lakes, composed of four small lakes (< 0.1 ha) marked in Figure 1 as object A and two large lakes, marked as objects B and C (area of about 7 and 3 ha, respectively). The stream flows through objects A and B. Object C retains spring water and constitutes a tributary of the main stream. All lakes are shallow, with a maximum depth of less than 3 meters.

Water sampling and analysis

Stream water was studied at monthly intervals during 2013-2014. Eight sampling stations were distributed down the stream according to Figure 1. Their interpretational significance is included in Table 1. Water temperature, pH (CPI 551, Elmetron), conductivity (CC 315, Elmetron) and dissolved oxygen (HI 9146) were determined in the field. 0.5 litre of water was taken in PET bottles for laboratory analysis. The samples were analysed immediately after arriving in the laboratory, to determine the content of major cations (Ca^{2+}, Mg^{2+}, K^+, Na^+, NH_4^+) and anions (SO_4^{2-}, Cl^-, NO_3^-, PO_4^{3-}) by an ion chromatography technique (881 Compact IC PRO, Metrohm). Moreover, the concentration of HCO_3^- was determined by titration using hydrochloric acid. Before the analysis, water samples were filtered through a 0.20 μm sterile syringe filter and diluted with deionised water in a ratio of 1:4. Metrosep C4 250/4.0 and Metrosep A Supp 5 250/4.0 analytical columns equipped with Metrosep C4 Guard/4.0 and Metrosep A Supp 4/5 Guard 4.0 precolumns were used. The accuracy of the output and QA/QC were based on certified reference material (Multi-element ion chromatography anion standard, certified 89 866-50ML-F, Fluka, France).

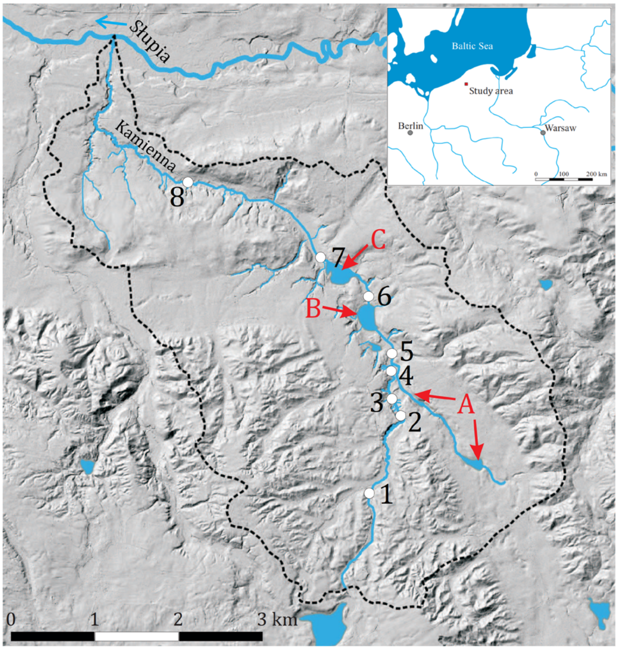

Fig. 1. Location of sampling points (numbers 1-8) and objects of small retention system (A-C) in the valley of the Kamienna Stream

Table 1

Interpretational significance of the sampling points

Sampling point number	Significance
1	upper course of the stream, first sampling point
2	a point before large spring niche covered by riparian forest
3	a point behind large spring niche covered by riparian forest
4	a point before headwater tributary carrying water from retention object A
5	a point behind headwater tributary carrying water from retention object A
6	a point behind retention object B
7	a point behind tributary carrying water from retention object C
8	lower course of the stream, last sampling point

Statistical analysis

Average seasonal temperatures, pH, conductivity and content of the cations and anions studied were calculated based on the results of our analyses. Moreover, the percentage coefficients of the variability in time were calculated for the individual sampling points (V_t) and along the stream (V_s) for the parameters mentioned above. Linear correlation coefficients between the ions studied were calculated as well.

RESULTS AND DISCUSSION

Water temperature is an important factor influencing the intensity of physical and chemical processes and the biological activity of organisms living in water bodies (WEBB et al. 2008, ZHANG et al. 2015). In riverine systems, water temperature is affected by a number of environmental factors, which influence its spatial and temporal variability. Spatial variability is caused by the temperature of supplying waters (spring water, drainage water, surface runoff, tributaries), cooling or warming effects of different environmental components, river channel morphology and water flow intensity. Temporal dynamics is controlled mainly by seasonal variability of weather conditions. In the studied stream water temperature ranged from 1.2 to 17.7°C, reflecting a seasonal effect (V_t = 51.2-69.4%). It has changed also down the stream (V_s = 7.64-79.8%) – Figure 2. Spatial variability was lower during the winter and spring as compared to summer and autumn; however, temperature increased downstream despite the season. During the summer and autumn, the effect of the retention system, in particular object B, is clearly visible. Water flowing through object B warmed by approximately 7°C. However, the temperature sharply decreased further downstream. Retention objects A and C did not influenced water temperature significantly.

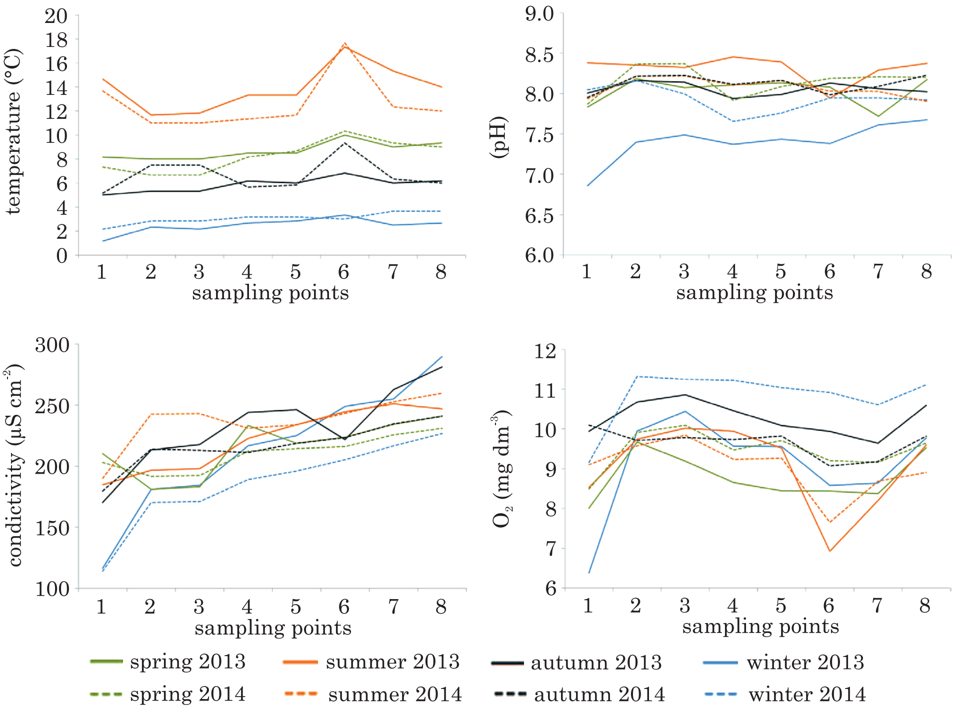

Fig. 2. Average seasonal temperatures, pH, conductivity and oxygen content in water down the Kamienna Stream

The lack or limited warming effect of retention objects A and C and quick cooling of stream water behind the object B can be due to tree canopy coverage, which is confirmed by the studies of Studinski et al. (2012) and Janish et al. (2012). However, precise estimation of the role of this factor would be difficult based on the data obtained.

Water pH was typical for lowland headwater streams of northern Poland (Florek et al. 2009, Mazurek 2010) and ranged from 6.9 to 8.5 based on quarter means (Figure 2). Its variability down the stream was low and tendencies were unclear. Thus we can conclude the effect of the small retention system on pH was not confirmed. Water in the upper course of the stream rapidly saturated with dissolved O_2 and then slightly decreased with distance from sampling point 2 (V_s = 2.4-22.5%). The effect of the retention system was observed during the summer and was most clear for object B. Values for dissolved O_2 (on average 6.38-11.32 mg dm^{-3}) correspond with data of Jekatierynczuk-Rudczyk (2006), Mazurek (2010) and Chomontowska, Kryjan (2014) for headwater ecosystems of northern Poland. The noted concentrations of dissolved O_2 in the studied stream did not differ significantly compared to that observed in small spring water outflows in its upper course (Parzych et al. 2016, 2018).

Water conductivity reflects saturation with solutes. Atmospheric inputs, evaporite dissolution, minerals weathering, organic matter decomposition and anthropogenic inputs constitute major sources of dissolved substances in river waters (Zhang et al. 2015). However, importance of these factors varies among the individual ions, geological structure and land use of catchment. In the studied stream, conductivity changed from 114.0 to 289.7 μS cm^{-2}, increasing down the stream (V_s = 5.6-27.8%) – Figure 2. The largest increases were recorded during the winter, when low temperature promotes solubility of gases, especially CO_2 in flowing water. Rapid increasing tendency in the content of solutes is typical for headwater streams (Mazurek 2010). The effect of the retention system was not significant.

Calcium is usually a major cation in groundwater and surface waters. The weathering of rocks and soil mineral components containing carbonates constitute a major source of this element. Our previous studies showed that soils of the catchment of the Kamienna Stream are relatively poor in this element (Jonczak 2013). Ca^{2+} concentration increased downstream and ranged from 8.34-52.48 mg dm^{-3} in its upper course to 47.93-89.64 mg dm^{-3} at the last sampling point (Vs = 7.0-76.7%) – Figure 3, but the small retention system had no significant effect on Ca^{2+} concentration. The content of Mg^{2+} changed from 0.25 to 4.20 mg dm^{-3}, showing large spatial (V_s = 34.6-172.8%) and temporal (V_t = 55.2-92.3%) variabilities (Figure 3). However, it is difficult to link temporal variability with seasons. Meanwhile, it seems to mark the impact of small retention objects. At sampling point 6 (behind retention object B) we can see a considerable increase in the content of magnesium. This trend is likely explained by the inflow of Mg rich water from springs

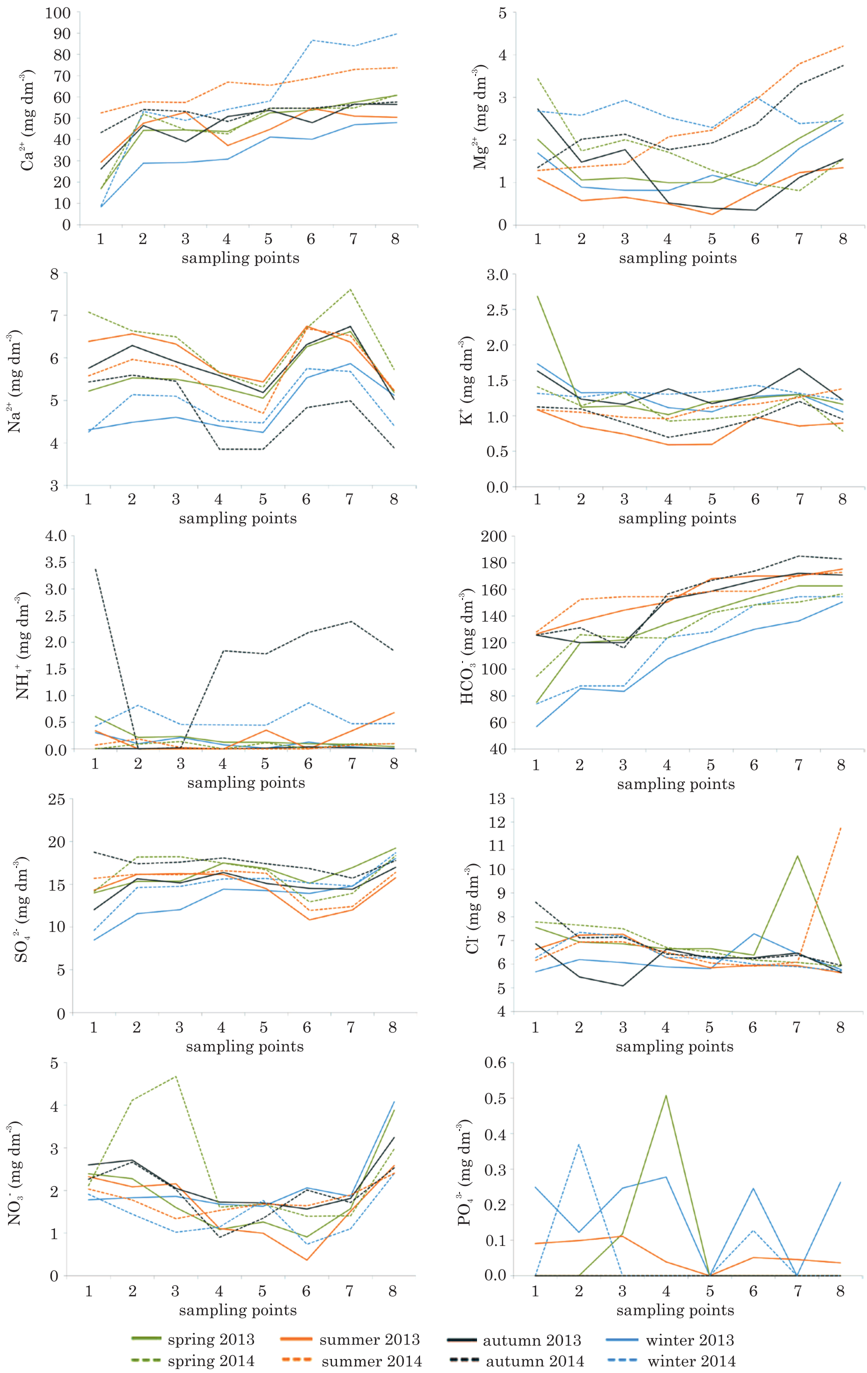

Fig. 3. Average seasonal contents of cations and anions down the Kamienna Stream

distributed along the shore zones of objects B and C or by an influx of litterfall and its decomposition. However, the results obtained do not allow determine significance of these two factors.

The content of Na^+ ranged from 3.85 to 7.60 mg dm^{-3}, reaching maximum values during the spring and summer periods (V_t=12.5-30.4%) – Figure 3. A decreasing trend was noted down the stream to the sampling point 5 (V_s = 8.7-83.0%). Water flow through retention objects resulted in increasing content of the element despite season of the year. Potassium content was in general lower and ranged from 0.59 to 2.68 mg dm^{-3}. It was relatively stable over time and down the stream. Average quarter concentrations of Na^+ and K^+ were comparable with data of FLOREK et al. (2009) for the left-bank tributaries of the Wieprza River located about 40 km NW from the studied stream, as well as by MAZUREK (2010) for headwater system of the Parsęta River.

The content of NH_4^+ is affected mainly by anthropogenic factors, particularly intensive farming (KOC, CYMES 2004) and urbanization (ROTHWELL et al. 2010). In forest ecosystems, including soil solution, ground water and surface water, ammonium occurs usually in traces due to limited production and intensive uptake by plants (PARZYCH et al. 2017). In the studied stream, it has changed from 0.00 to 3.37 mg dm^{-3} (V_s = 0.0-6.9%; V_t = 184.0-347.8%). Despite the observed large spatial variability, tendencies were unclear.

The content of HCO_3^- in water bodies is controlled by dissolution of atmospheric CO_2 and weathering of carbonates. Concentration of this ion in river systems is related to water flow intensity and temperature (JONCZAK 2010, ZHANG et al. 2015). In the studied stream, HCO_3^- showed relatively low variability (V_s = 4.8-32.8%; V_t = 7.5-34.7%), showing increasing tendency down the stream (Figure 3). The effect of the small retention system was not significant. The highest concentrations of HCO_3^- were observed during the summer or autumn, whereas the lowest occurred during winter.

Sulphates and chlorides constitute dynamic components of groundwater and surface waters, and their concentrations are strongly controlled by geological structure of the catchment and use type (JONCZAK 2010, ZHANG et al. 2015). In the studied stream, the content of SO_4^{2-} ranged from 8.49 to 19.21 mg dm^{-3}, whereas Cl^- from 5.08 to 11.81 mg dm^{-3}, which is typical for surface waters of young-glacial landscape of northern Poland (MAZUREK 2008). In the studied object, contents of SO_4^{2-} were relatively stable along the stream (V_s = 6.9-24.2%) and over time (V_t = 8.2-28.1%). This suggests the stability of the studied afforested headwater ecosystem, which has not been disturbed significantly by a retention system. Water flow through dammed lakes caused only a slight reduction in content of this component (Figure 3). Larger variability showed Cl^- (V_s = 3.1-74.0%; V_t = 7.2-55.8%). Results of the studies of JEKATIERYNCZUK-RUDCZYK (2006) showed that significant quantitative transformation of this component in water takes place already in a hyporeic zone.

Nitrogen and phosphorus are usually deficient components in natural and semi-natural environments, particularly in forest ecosystems. It is confirmed by active mechanisms of uptake of these elements by plants (McGill, Cole 1981) and their translocation from leaves to shoots before dropping (Dziadowiec et al. 2007). Nitrogen and phosphorus also constitute major limiting nutrients in freshwater ecosystems (Conley et al. 2009). However, riparian forests, as transient zones strongly affected by groundwater, can be an exception in this range. The results of our studies showed that Histosols of headwater areas in the Kamienna Stream valley are relatively abundant in nitrogen yet poor in phosphorus (Jonczak et al. 2015). Vertical distribution of nitrogen fractions in these soils is strongly affected by underground water flow from outflows towards the stream. The studies of Kortelainen (1997) showed the importance of headwater peatlands as a source of mineral nitrogen. Moreover, the author noticed a significant increase in nitrogen concentration affected by a temperature gradient along a north-south transect. In the studied stream, contents of NO_3^- and PO_4^{3-} ranged from 0.37 to 6.67 mg dm^{-3} and from 0.00 to 0.51 mg dm^{-3}, respectively (Figure 3). Temporal variability in concentration of these ions was not large and tendencies were not clear. Along the stream, we can see a slight reduction in nitrates content after flowing through the retention objects and then a considerable increase at last sampling point. The observed tendency can be explained by retention of nitrogen by organisms living in dammed lakes. Phosphates showed unclear tendencies.

The studied ionic components of stream water did not show significant correlations in most cases (Table 2). There are some positive interactions between Na^+ vs K^+, Ca^{2+} vs Mg^{2+}, Ca^{2+} vs HCO_3^-, SO_4^{2-} vs HCO_3^-, and negative between Na^+ vs NH_4^+.

Table 2

Linear correlation coefficients between the content (mg dm^{-3}) of the studied ions

	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	PO_4^{3-}
Na^+	**0.424**	0.239	-0.076	**-0.553**	0.336	0.225	0.266	0.175	-0.044
K^+		-0.057	0.096	-0.336	-0.107	-0.071	0.224	0.192	-0.004
Ca^{2+}			**0.410**	-0.064	**0.514**	0.356	0.008	0.053	-0.130
Mg^{2+}				0.185	0.091	0.036	0.121	0.091	-0.066
NH_4^+					0.021	0.113	0.052	-0.118	-0.019
HCO_3^-						0.505	0.126	0.062	-0.176
SO_4^{2-}							0.273	0.225	-0.073
Cl^-								0.126	-0.008
NO_3^-									-0.041

In bold correlations statistically significant at $p < 0.05$

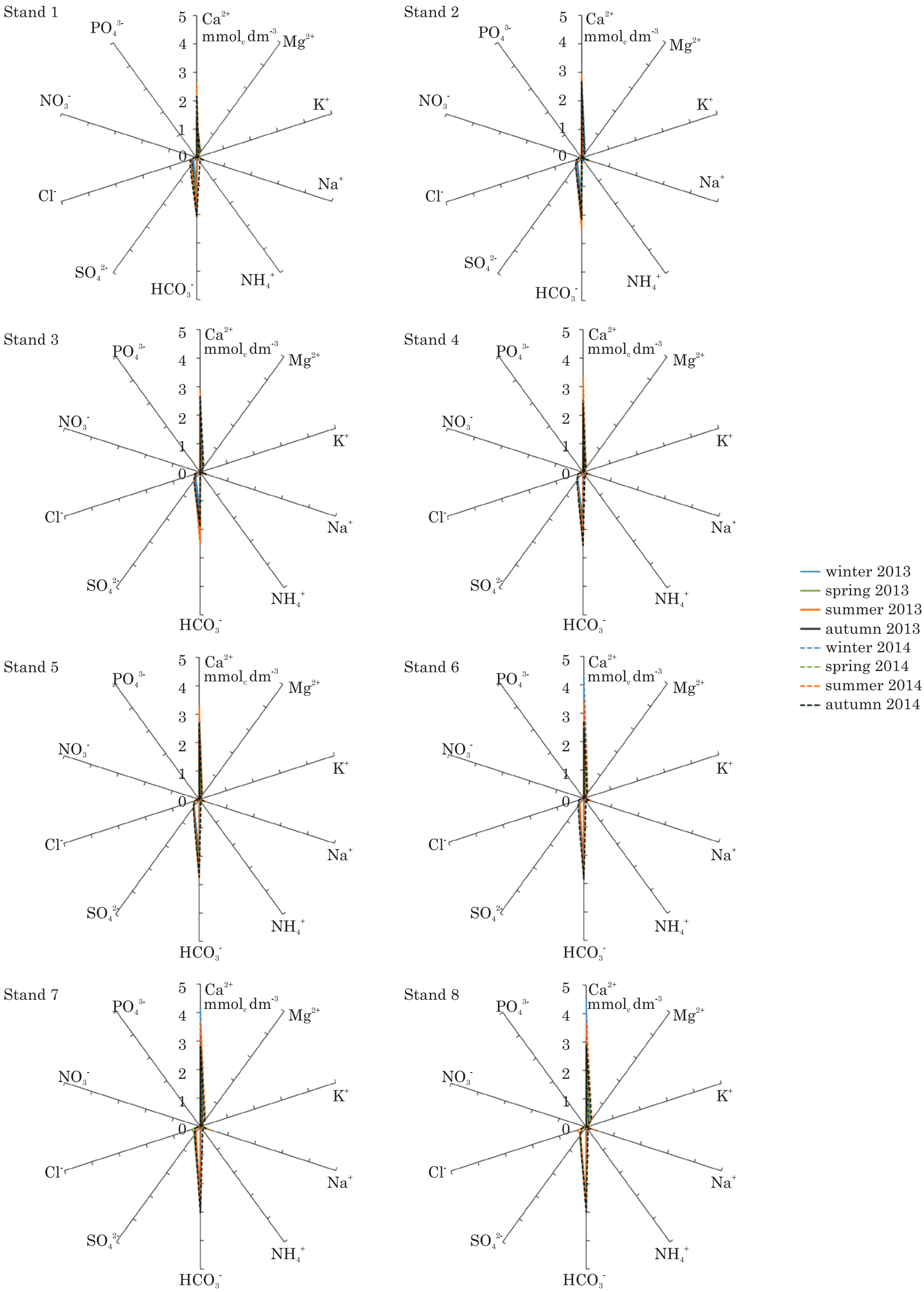

Fig. 4. Ionic balance of water at sampling points 1-8 during the seasons of 2013 and 2014

Water of the studied stream had calcium-bicarbonate character despite the sampling point and season of the year (Figure 4). Therefore, it can be concluded that small retention system had no significant effect on ionic balance. The observed predominance of Ca^{2+} and HCO_3^- is typical for groundwater and surface waters of northern Poland (Florek et al. 2009, Jonczak 2010, Mazurek 2010).

CONCLUSIONS

The results of our studies showed limited effects of the small retention system (dammed lakes) allocated in afforested catchment of the Kamienna Stream on temperature and ionic composition of stream water. Warming effect was observed only for one retention object, and it was cancelled at short distance behind the lake, perhaps due to effect of tree canopy coverage. Water flow through retention objects resulted in considerably increased contents of Na^+ and slightly lower contents of SO_4^{2-} and O_2. Conductivity and contents of Ca^{2+} and HCO_3^- showed continuous increases down the stream not showing fluctuations indicating influence of retention objects. The mentioned above ions constituted major ionic components of the studied waters, which is typical for surface waters of northern Poland. Therefore, waters had calcium-bicarbonate character at every sampling point and over the whole study period. The remaining ionic components showed irrelevant or unclear tendencies.

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