Journal of Hydrology 564 (2018) 605–618

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

The effects of different land use and hydrological types on water chemistry of young glacial ponds

Łukasz Pietruszyński, Roman Cieśliński*

University of Gdansk, Department of Hydrology, Bażyńskiego 4, 80-952 Gdańsk, Poland

ARTICLE INFO

This manuscript was handled by Marco Borga, Editor-in-Chief, with the assistance of Daniele Penna, Associate Editor

Keywords:
Ponds
Water quality
Land use
Young glacial areas
Closed circulation areas

ABSTRACT

The study aims to examine the effect of ponds on changes in water quality in a young glacial river catchment. The goal was to identify situations where a periodic hydrographic network is formed in outflow-free areas, which is connected with a higher order receiving area, as well as to study the circulation of matter in this type of system. This study answers the following key question: Do ponds affected by areal pollution substantially affect water quality in streams in periods where they become joined with the hydrographic network? The purpose of the research was to identify patterns associated with the functioning of ponds in young glacial areas in northern Poland on the example of the Borucinka catchment. Ponds were selected in order to generate a study sample characterized by different types of land use, local hydrology, and pond surface area. The study focused on the effects of catchment land use on pond water quality and the effects of periodic changes in local hydrology (linkage of surface flows with bodies of water) on pond water quality. Research has shown that land use in a pond catchment yields a substantial effect on pond water quality. The basic reason for the higher concentration of selected ions is close proximity to farms that generate wastewater, which reaches bodies of water in the study area. Seasonal changes in the concentration of biogenic substances were not observed in ponds. Only notable changes in the concentration of total nitrogen were observed due the episodic formation of a hydrographic network consisting of a collection of linked depressions. One of the more surprising findings was that permanently isolated ponds, which theoretically collect catchment pollutants all the time, are characterized by good hydrochemical conditions.

1. Introduction

Ponds are a very important part of geographic space in young glacial areas due to their capacity to retain water as well as their numerous hydrologic functions and biological value (Oertli et al., 2005). They are highly susceptible to external influence due to their specific morphometry, ecological characteristics (Davis et al., 2008, Oertli et al., 2009), as well as a frequent lack of connectivity with rivers (Gerke et al., 2010).

The location of a pond in a given type of catchment yields a number of consequences associated with pond functioning and the formation of a specific ecological state. In the past, most researchers argued that ponds form closed circulation areas, which are not part of a main hydrographic system. This would make ponds a physical trap for pollutants moving across a catchment (Waldon, 2012). However, more recent research suggests that ponds sometimes do connect with other bodies of water, which produces consequences not only in terms of water circulation and water resources in a catchment, but also in terms of water chemistry through a loss of pollutants previously deposited therein. Tiner (2003) argues that the pond and pond catchment system constitutes an isolated feature of geographic space. At the same time, due to natural and anthropogenic changes, ponds and their catchments can form entire hydrographic systems along with other bodies of water in their vicinity if a hydraulic connection is created in one way or another.

Ponds strongly affect catchment water circulation by serving as a natural reservoir of rainwater (Brooks, 2004). The research literature suggests that many natural determinants (physical, biological, geographic, hydrologic, meteorological) affect pond water chemistry (Hayashi et al., 2004). However, it is the intensification of agriculture that represents the greatest threat to ponds by indirectly accelerating the gradual decline of ponds through the excessive use of phosphorus fertilizers (Schoumans et al., 2014, Yan et al., 2016). Excessive phosphorus in water contributes to the massive development of phytoplankton organisms. As a consequence, the transparency of the water is reduced. Submerging vegetation subsides. This is the effect of

* Corresponding author.
E-mail address: georc@univ.gda.pl (R. Cieśliński).

https://doi.org/10.1016/j.jhydrol.2018.07.049
Received 11 March 2018; Received in revised form 17 July 2018; Accepted 19 July 2018
Available online 20 July 2018

deteriorating light conditions. This leads to the reconstruction of the existing fauna. Excessive supply of phosphorus also leads to the depletion of oxygen resources in the bottom layer of water reservoirs, which leads to the disappearance of deep-water fauna. Also, climate change adversely affects the ponds and, above all, on the vegetation structure, hydrologic function, and biodiversity (Johnson and Poiani, 2016).

Changes in pond water chemistry should be associated with vertical water exchange or atmospheric and evaporation as well as horizontal water exchange in the form of groundwater influx and loss. For this second element, Winter and Rosenberry (1995), Turner and Townley (2006) and Kacimov (2007) indicate that lakes and ponds in lowland areas are usually hydraulically connected to a shallow groundwater system. In effect, pond water chemistry should be reflective of rainwater chemistry or groundwater chemistry. However, this is not the case in many instances. In such cases, it is reasonable to presume that surface water influx occurs at certain times of the year thanks to changes in catchment water levels (Golus and Bajkiewicz-Grabowska, 2016). Hence, pond water chemistry depends first and foremost on the source of water.

Ion chemistry of ponds and lakes water provides important information about the sources of dissolved ions, weathering, and hydrogeochemical processes as well as anthropogenic activities taking place in the lake environment (Singh et al., 2016). While ponds do differ in terms of their hydrologic origin, it is also a fact that recharge is dominated by two sources of water – atmospheric and groundwater influx. It is also quite possible that other environmental sources affect the water chemistry of ponds (Lowenstein and Risacher, 2009). First and foremost, this is applicable to land use in the studied pond catchments, relief, atmospheric precipitation, anthropogenic pollution, and seasonal plant growth patterns. Yet other factors that may affect pond water chemistry include pond morphometry (Lischeid and Kalettka, 2012). Work on ponds in northern Germany (Lischeid and Kalettka, 2012) has shown that these key factors explain 90% of variance in pond water chemistry. Finally, remaining factors include land use, agricultural pollution, primary production, and type of soil cover. It is important to note that ponds are highly sensitive to external factors due to their unique morphometry and hydrology (Gałczyńska et al., 2011).

The purpose of the paper is to discuss changes and differences in water chemistry in selected ponds based on water exchange type (outflow-free, flow-through) and land use in the direct catchment – i.e. woodland, agricultural, immediate vicinity of a farm. This will make it possible to assess how different water circulation patterns and land use affect water chemistry in the studied ponds. The research results will help us understand how ponds function as well as how they are comparable to one another.

2. Methods

Most of the research consisted of fieldwork, which commenced in November of 2012 and was completed in October of 2014 yielding a total of 15 field excursions. The study area consisted of the Borucinka river catchment in the Kaszubski Lake District found in northern Poland, as an example of areas covered by the last glaciations. Ten ponds were studied in this study area (Figs. 1 and 2). Most of the ponds were located in the western part of the studied catchment. This particular area is characterized by significant seasonal changes in the local hydrographic structure manifested in the form of a periodically emerging hydrographic network that connects ponds together. This unique study area made it possible to determine the effects of changes in local water circulation patterns on pond water chemistry. Research has shown that ponds no. 2, 4, and 8 are permanently outflow-free, while the remaining seven ponds are periodically connected with the area river network. In addition, ponds were selected for research purposes based on key differences in catchment land use: (1) agricultural land use, (2) forest land use, (3) farm-adjacent land use or very close proximity to a working farm. This choice of ponds made it possible to determine which forms of land use produce the largest effects on pond water quality.

A multi-parameter HACH HQ40D gauge was used in the course of the fieldwork to determine water parameters such as pH and electrolytic conductivity. Water samples collected in the field were then analyzed at the Hydrochemical Laboratory at the Department of Hydrology at the University of Gdańsk. The concentrations of selected cations (Na^+, NH_4^+, Mg^{2+}, K^+, Ca^{2+}) as well as anions (Cl^-, NO_2^-, NO_3^-, PO_4^{3-}, SO_4^{2-}) were determined using a Dionex ICS-1100 capillary ion chromatograph with IonPac AS 22 (4 × 250 mm) and CS16 (5 × 250 mm) columns at 30 °C, using Dionex concentrate AS 22 and methanesulfonic acid (MSA) as a eluents for the analysis of anions and cations, respectively. For the filtration of water samples we used 0,45 µs Milliphore membrane. Moreover, total nitrogen (Ntot) and total phosphorus (Ptot) were determined via colorimetry using a Merck Nova 400 spectrophotometer.

Instrumental calibration was carried out using Multi-element standard solution for cations (Ca^{2+}; K^+; Mg^{2+}; Na^+), Multi-element IC Standard Solution for anions (Cl^-; SO_4^{2-}; NO_3^-; PO_4^{3-}; NO_2^-) and Mono Element Calibration Solution for ammonium (NH_4^+). Ion calibration was based on 7 points obtained diluting suitably batch solutions in the range 0.1–50 ppm. Experimental uncertainty was determined by 10 replicates of a suitable standard solution with a concentration level of ions enclosed within the calibration concentration range. The margin of error for the analyses was less than 2%.

In addition, water levels were measured in the field using gauges affixed in ponds. The first measurement was assumed to be a base level, while subsequent measurements were used as data to be compared with the base water level in order to assess fluctuations in the water level.

Meteorologic data were obtained from the Meteorologic Station of the University of Gdańsk (located in Borucin). The classification of temperature conditions and precipitation for each studied month was done based on a method proposed by Miętus et al. (2005).

The studied ponds fall within three different categories of land use: (1) agricultural, (2) woodland, (3) farm-adjacent. The dominant type of land use in the study area is agricultural – mostly arable land. While this is the primary land use in each of the studied areas, only some study areas were classified as agricultural in nature. The share of woodland is relatively low, although ponds surrounded by relatively large woodland areas were classified as woodland type, as forested areas provide some measure of protection from the influx of pollutants. Some of the studied catchments were located adjacent to working farms featuring residential infrastructure, which may yield substantial amounts of pollution to ponds. These ponds were classified as farm-adjacent (Table 1).

The work uses various statistical calculations, comprehensive Perkal Index and grouping by Ward method, among others.

3. Results

3.1. Meteorological situation during the research period

The annual atmospheric precipitation total for the study period (hydrologic years 2013 and 2014) was lower than the long-term average for the period 1961–2000 (668.5 mm) and stood at 614.9 mm in 2013 and 598.2 mm in 2014. However, average annual air temperatures were higher than the long-term average during the study period (6.8 °C) and stood at 7.3 °C in 2013 and 9.0 °C in 2014. The highest average monthly air temperatures were noted in July (18.1–20.2 °C). Fig. 3 shows the distribution of monthly atmospheric precipitation totals and air temperatures.

3.2. Changes in the amount of water stored in each pond

Research has shown that water levels in the studied ponds change