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Kopalińskie Lake as an example of an anthropogenic reservoir of the southern Baltic Sea coast

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Abstract: The aim of this study is to discuss the water balance of Kopalińskie Lake, which is one of a few reservoirs on the Polish coast formed from anthropogenic activity. To realize this aim, lake basin morphometry and catchment hydrography were characterized. Moreover, the influence of the sea and the physico-chemical characteristics of the lake water were defined. As a result, the main characteristics of the lake and its catchment were found. Common characteristics of Kopalińskie Lake, as well as the characteristics that differentiate this reservoir from the other coastal lakes located on the Polish coast are presented in this work.

Key words: Kopalińskie Lake, coast, catchment, anthropogenic reservoir

Introduction

The southern Baltic Sea coast is the location of many lakes which have different lake basin genesis. In most cases (about 70%), these are coastal lakes (sandbar lakes) and the morphometric characteristics of their basins have a high similarity (Choiński 2000). However, there are varied hydrographic conditions in terms of water quality and sub-catchments. Coastal lakes differ also in terms of hydro-genesis of their waters, which should be connected with a number of processes and occurrences that affect each lake locally. Hydrological diversity and quality of reservoirs is mainly determined by the interaction of land and sea, and anthropogenic activity, which has been observed in the past two decades. Depending on which of the environments, marine or land, interacts more strongly, the water in the reservoir is fresh or brackish (Cieśliński 2011).

Kopalińskie Lake is one of the objects that until now have not been the subject of any detailed research and studies. It is a lake located on the southern Baltic Sea coast, which was formed by human activity. Moreover, the system of the hydrographic network in its catchment is presented in an interesting way.

The goal of the study is to provide basic physicolimnological and hydrochemical characteristics of a lake located on the coast which was formed and developed by anthropogenic activity. Kopalińskie Lake was chosen as an example of such a reservoir. That is the only object of this type, located in close proximity to the Baltic Sea. In addition to Kopalińskie Lake, only Żarnowieckie Lake has the characteristics of an anthropogenic reservoir. Unlike Kopalińskie Lake, Żarnowieckie Lake was formed naturally. Żarnowieckie Lake gained anthropogenic characteristics after a hydroelectric power station was built (in the early 1980s).

Kopalińskie Lake is situated on the Kashubian coastal zone, in the province of Pomerania about 0.5 km from Lubiatowo village, about 1.0 km from Kopalino and about 1.5 km from the sea.

Methods

The main research can be divided into field and laboratory work. Field work consisted of collecting samples of surface and near bottom water from Kopalińskie Lake. Collected samples were analysed by specifying physico-chemical characteristics. Also for that purpose water samples on tributaries and outflows from the lake were taken. The location of measuring points is presented in Figure 1. On the linear objects flow measurements were performed using

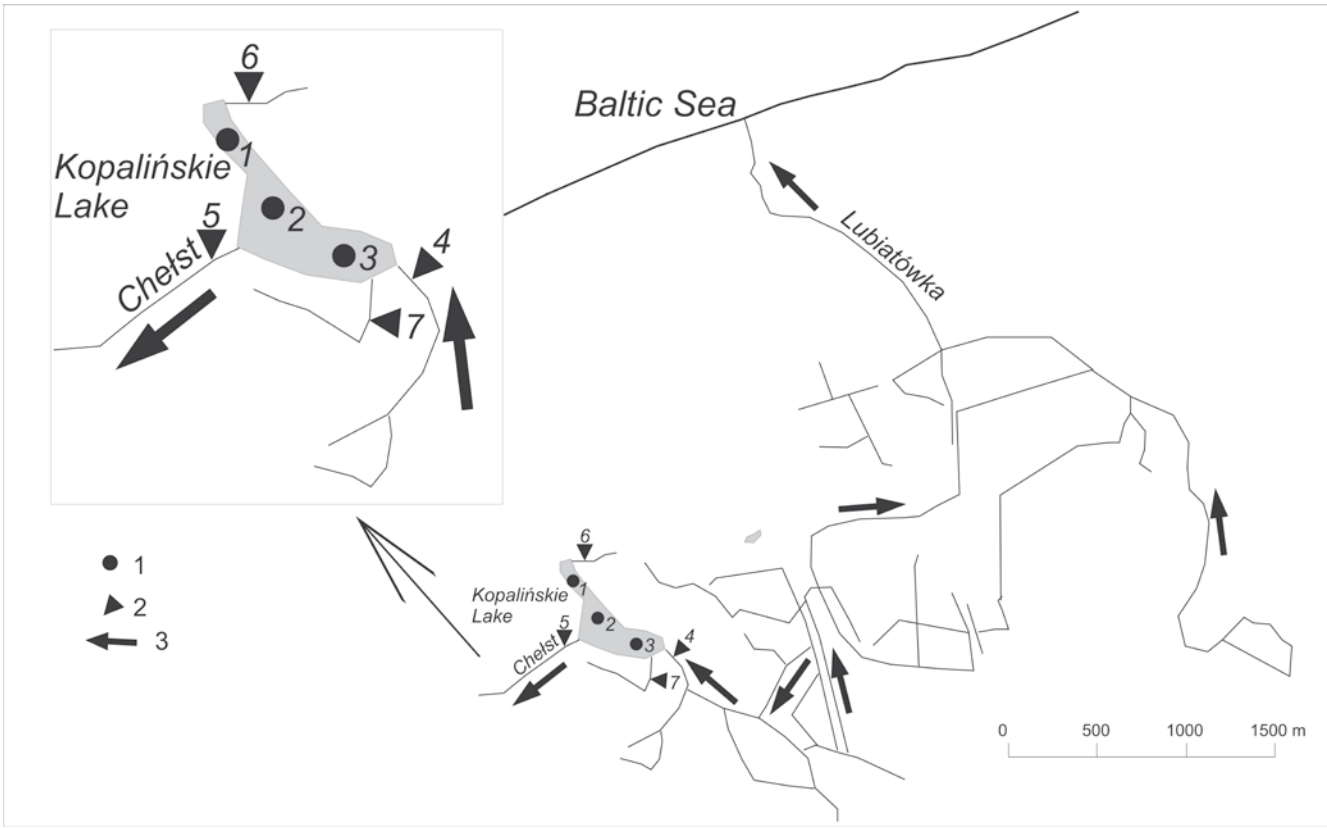


Fig. 1. Location of measuring points on Kopalińskie Lake and its tributaries: 1 – water sampling point on the lake, 2 – point of hydrometric measurements and water sampling of streams, 3 – the direction of water flow

an Argonaut flowmeter (made by Sontek). Probing depths in the lake was performed in July 2009 using a Fish Finder sonar and ETREKS GPS (made by Garmin). A water gauge was installed in the eastern part of the lake without levelling. The results allowed the authors to evaluate only the variability variations of water level in the lake. Readings were taken once a month. In 2009-2010, field work was carried out with a month time step.

Laboratory testing was based on defining the conductivity of the reaction rates and the concentrations of chloride, sodium, potassium, calcium, magnesium, sulphate, bicarbonate, nitrate, phosphate and ammonia in water samples.

Chloride was determined by argentometric titration (Mohr method), sulphates were determined by the nephelometric method using a Spectroquant spectrophotometer (made by WTW), carbohydrates were determined by titration, and magnesium and calcium by the wersenian method. Sodium and potassium were determined using a set of flame photometry SHERWOOD SCIENTIFIC 410. The electrical conductivity and pH were determined using a MULTI350i gauge (made by WTW). Nitrate was determined by the colorimetric method of sodium salicylate by using a DR 890 photometer (made by HachLange) and phosphates were determined by molybdates of stannous chloride as a reductant using a DR 890 photometer (made by HachLange).

Results

Hydrographical characteristics of Kopalińskie Lake catchment. Kopalińskie Lake with an area of 8.37 ha (based on our own field work), has a catchment of a low hydrographic network, which consists of small canals and streams. According to Choiński (1991), its area is 3.0 ha, while by the planimetric method its area is 5.6 ha. In the lake catchment there are no greater wetlands or ponds. On three sides it is surrounded by forest. Kopalińskie Lake can be divided into two parts: a larger part (northern and central part of the lake) and a smaller bay (southern part of the lake). The whole lake during the summer period is heavily covered with floating vegetation (more apparent in the southern part of the lake). Moreover, the roots of

trees growing around the lake "grow into" the water. One tributary flows into the lake from the north and two other tributaries from the south. These are small streams. One of the tributaries on the south side is a channel (measuring point No. 7), though no flow is observed in it (stagnant water). There is one outflow from Kopalińskie Lake – Chełst River, which is located in the western part of the lake. The entire hydrographic system of Kopalińskie Lake is strongly related to Lubiatówka River, which connects to the sea.

Water flow in streams flowing into Kopalińskie Lake during the study period varied from 0.0 (stagnant water) at measuring point No. 6 (northern part) to 0.1 $m^3 s^{-1}$ at measuring point No. 4 (southern part) (Fig. 2). The average flow was 0.02 $m^3 s^{-1}$ at measuring point No. 6, and 0.04 $m^3 s^{-1}$ at measuring point No. 4. During this time the flow varied from 0.02 to 0.18 $m^3 s^{-1}$ at the only outflow from the lake (Chełst River – measuring point No. 5) (Fig. 2). The lowest flows on inflows and outflow were observed in January, February and November, and the highest in March and July. Two calendar years analysed in terms of the results were similar.

All streams in accordance with the division by Dynowska (1971) may be classified into groups characterized by a balanced regime, a simple spring, ground-rain-snow supply. Rapid increases in water flows are not observed in this area, even during periods of spring thaws. In the whole study period the observed flows formed at low levels.

Fluctuations in water level in Kopalińskie Lake. Throughout the study period water level fluctuations were observed from -10 cm to 30 cm of the initial level observed in January 2009, which is designated as 0 cm (Fig. 3). The amplitude of fluctuations in the study period was only 40 cm. This is much different from those observed in most coastal lakes, where the fluctuations during the year are greater than 100 cm (Choiński 2007). Only Lakes Sarbsko and Modła are similar to Kopalińskie, but even they have amplitudes greater than 50 cm (Cieśliński 2011). The highest water levels recorded in March of 2009 and 2010 amounted to 26 cm and 30 cm. The lowest levels were recorded in June 2009 (-5 cm) and in February and June 2010 (-6 cm and -10 cm). In the predominant period water level in the lake was above the initial one and only during six measurements was it less than 0 cm (Fig. 3).

Origin of lake basins. Kopalińskie Lake formed about 200 years ago, at a peat extraction area in the hollow formed after the extraction of peat, which was then filled with water. According to criteria by Choiński (2007) the lake can be classified as an anthropogenic lake, after exploitation. The bottom of the lake is silting (sediment dominated by soft-plastic), which results from its origin in the old peatland. The shape of the lake resembles the letter "L". Based on research from July 2009, the maximum depth of the lake is 3.3 m and the mean depth is 1.6 m. According to Cieśliński (2005) the maximum lake depth was 3.0 m. Obtained values of mean and maximum depths are

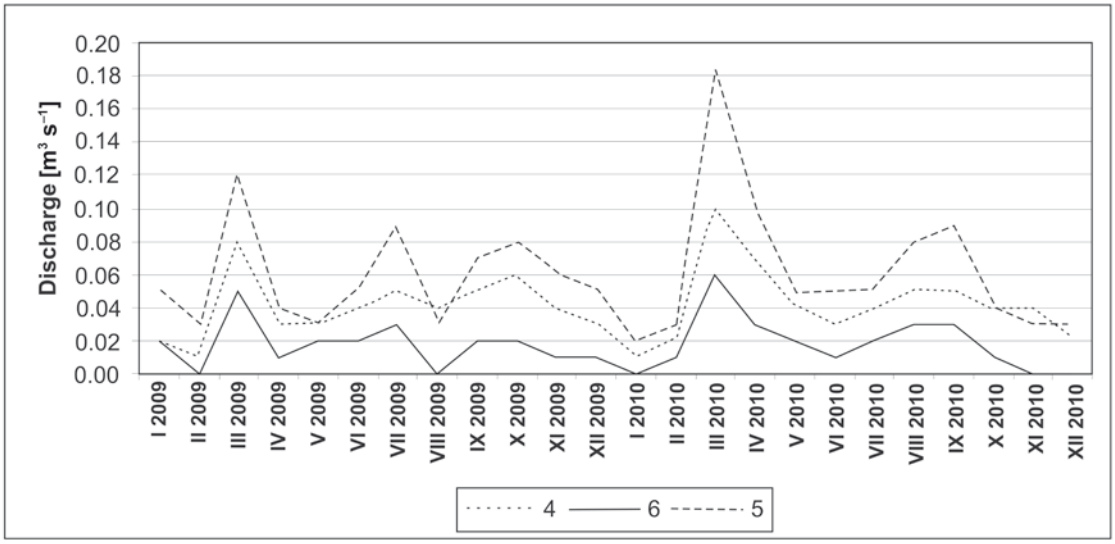


Fig. 2. Water flow in the tributaries to Kopalińskie Lake (No. 4, No. 6) and on the Chełst River (No. 5) in 2009-2010

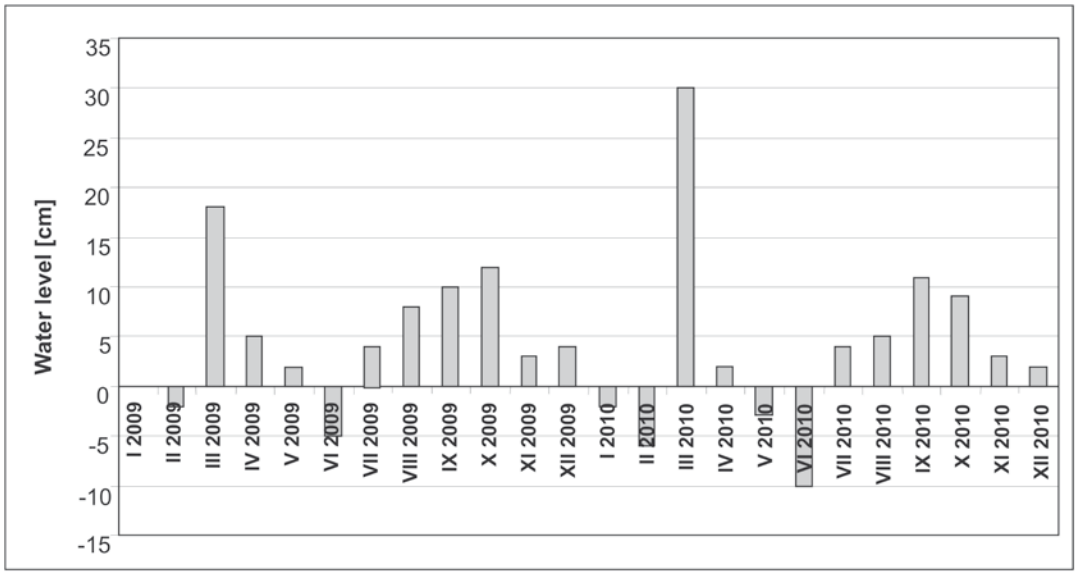


Fig. 3. Fluctuations in water level in Kopalińskie Lake in 2009-2010

typical for shallow coastal lakes (Choiński 2001). Isobath distribution is even across the lake basin. Right from the shore of the lake a significant decrease in depth, which is about 2.0 m, is observed and in the open parts of the lake depth significantly lower values of 0.9-1.5 m are recorded. However, in the southern part (bay) the lake is 0.7-0.8 m deep. Kopalińskie Lake formed in the old peatland, which causes the lake bottom to be heavily silted, but the water during the summer period has a good transparency (Cieśliński 2005).

Water chemistry of Kopalińskie Lake. The waters of Kopalińskie Lake are characterized by a typical physical-chemical composition, which is observed in fresh waters. According to the classification of Szczukariew-Prikłoński (Prikłoński and Łaptiew 1955) it has bicarbonate-calcium waters. The percentage distribution of all main ions is dominated by the bicarbonate ion (45%) and calcium (28.4%) (Fig. 4). Considering separately the distribution of anions and cations deviations from this distribution are not noticeable. The dominant anion is the bicarbonate ion (Fig. 5). The distribution of anions is as follows:

$$rHCO_3^- > rSO_4^{2-} > rCl^-$$

This distribution is typical for fresh waters (Berner and Berner 1987). In the analysis of the distribution of cations, the domination of one ion, calcium, can be seen (Fig. 6). Other cations are not significant. The distribution of cations is also typical for fresh waters and is subject to the following:

$$rCa^{2+} > rMg^{2+} > rNa^+$$

Based on observations of the variation of basic ion concentrations, a low of variability in time can be identified – evidenced by the maximum and minimum values (Table 1), whereas the average values indicate small concentrations throughout the study period (Table 1). In the case of spatial variability for several physico-chemical indicators (conductivity, sodium, calcium) concentration differences between

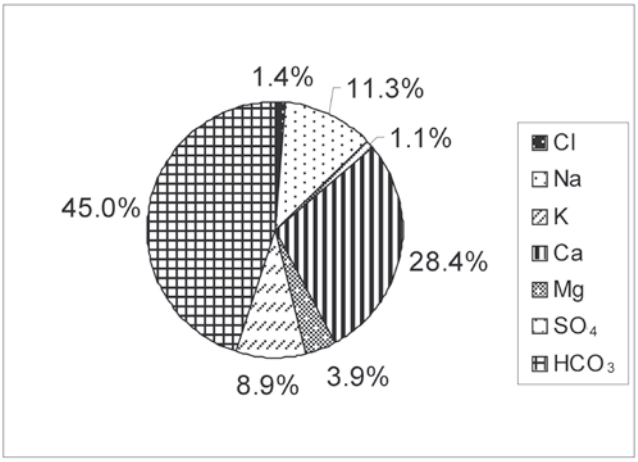


Fig. 4. Percentage distribution of the contribution of each ion in the water of Kopalińskie Lake

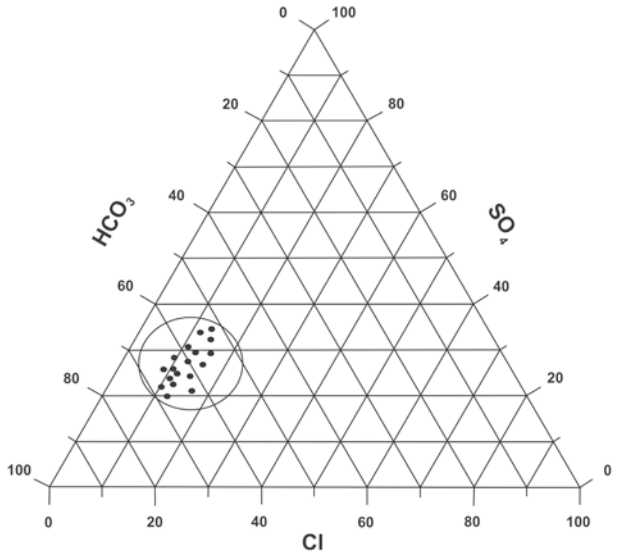


Fig. 5. Anion distribution in waters of Kopalińskie Lake

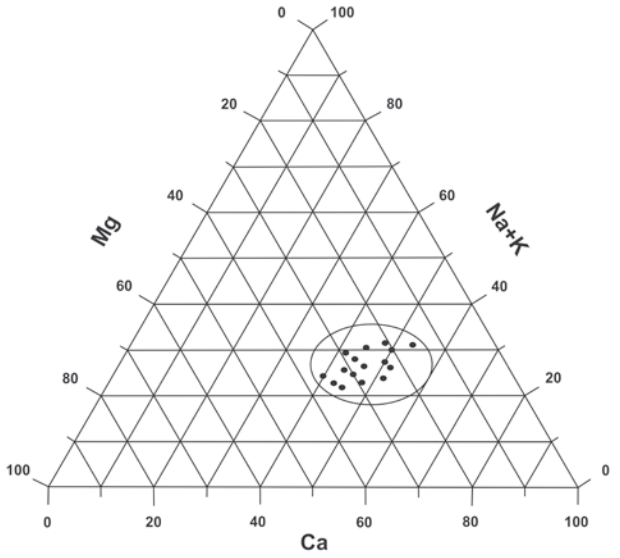


Fig. 6. Cation distribution in waters of Kopalińskie Lake

Table 1. Changes in concentrations of basic ions in the waters of Kopalińskie Lake in 2009-2010

Indicator	Unit	Minimum	Maximum	Mean
Chlorides	mg l^{-1}	3.0	8.0	3.8
Sodium	mg l^{-1}	2.8	6.1	3.5
Potassium	mg l^{-1}	1.5	3.0	2.2
Calcium	mg l^{-1}	36.6	51.2	43.9
Magnesium	mg l^{-1}	2.2	6.9	3.8
Sulphates	mg l^{-1}	31.1	42.0	35.7
Bicarbonate	mval l^{-1}	3.7	5.4	4.2
Conductivity	µS cm^{-1}	288.0	361.0	326.6

the northern and central and the southern parts were observed. For example, on 12.05.2009, the size of the conductivity in the northern and central part of the lake amounted to 344 and 348 µS cm^{-1}, when in the southern part it reached the value of 288 µS cm^{-1}, which is about 80% of those values.

The pH of water in Lake Kopalińskie was mostly neutral (7.0-7.5), though there were times when it displayed a slightly alkaline pH (9.0-9.2).

The value of dissolved oxygen was very variable and related to seasonality. The highest values of approximately 10.0 mg O_2 l^{-1} were reached by the lake water in spring and autumn. The lowest level of lake water was below 3.0 mg O_2 l^{-1}, reached in late summer and in winter, and also at the time when there was ice cover. In each period, as in most coastal lakes, a decrease in oxygen content with increasing depth was observed (Fig. 7). These reductions are quite large and can even reach 100% between the surface and near bottom layer.

In the case of primary ions significant differences between surface, near-bottom and interstitial waters are not observed (Fig. 8). These are differences of 2-3%. There also can occur not only decreases but also increases with depth. It can be concluded that in the lake due to the basin morphometry in any period the stratification of water is not formed. This demonstrates the high homogeneity of Kopalińskie Lake waters.

The main source of pollution of Kopalińskie Lake is the inflow of nutrients (nitrogen and phosphorus compounds). Biogenic substances get into the lake as a result of agricultural activity (artificial fertilizer runoff from fields and pastures), uncontrolled discharge of social and domestic wastewater and as a result of tourism and recreational activities during the summer. Consequently, a seasonal increase in their concentrations is observed. In the case of total nitrogen and nitrate concentrations, a decrease during the summer followed by a steady increase in the winter period (where the highest values are recorded) is observed. The amount of total phosphorus and phosphate increases during the summer (reaching a maximum), then decreases in the autumn, and increases in the winter. Ammonia is characterized by increased concentrations during the summer and a continued decline in the winter period (Fig. 9). In the case of nitrogen compounds, decreases or increases in their value in the waters of Kopalińskie Lake are closely re-

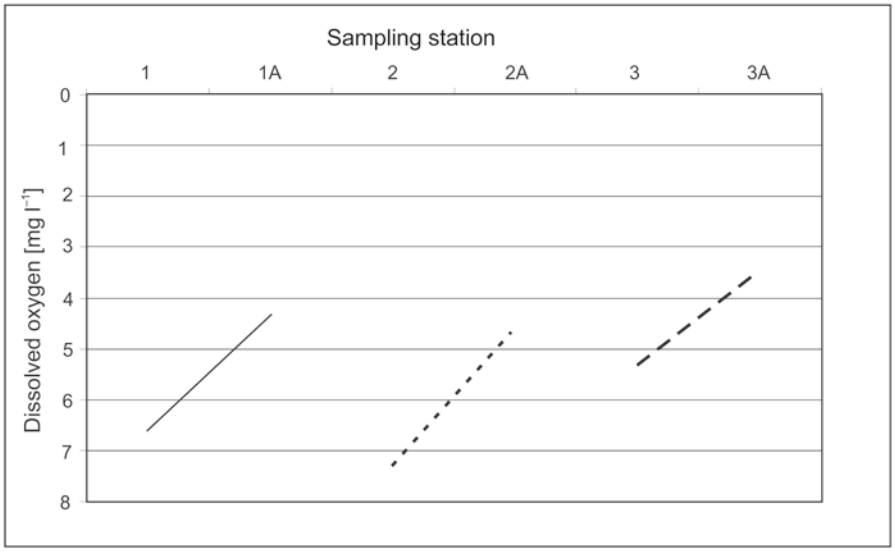


Fig. 7. The difference in size of dissolved oxygen in waters of Kopalińskie Lake between the surface (1, 2, 3) and near-bottom layer (1A, 2A, 3A) in 2009-2010

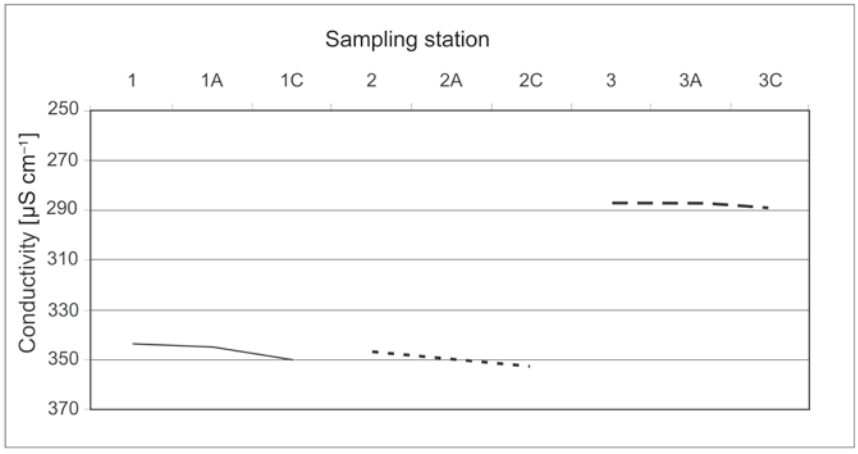


Fig. 8. The difference in size of conductivity in waters of Kopalińskie Lake between the surface (1, 2, 3), near-bottom (1A, 2A, 3A) and interstitial layer (1C, 2C, 3C) in 2009-2010

lated to the phenomenon of photosynthesis, biomass production and the period of fertilization. The volume of ammonia is closely related to human recreational activities, and the existence of waterfowl. Phosphorus compounds, by contrast, are related to the inflow of waste water, the field fertilization period and periodically the phenomenon of re-suspension of bottom sediments where significant amounts of phosphorus are accumulated. The confirmation of this thesis may be significant differences in mean values of total phosphorus and phosphates in the vertical layout as compared to other nutrients (Table 2). For all nutrients little differentiation between the surface and near-bottom layer is observed. Differentiation between the interstitial and near-bottom layer for phosphorus compounds is large: an increase in value by 135-140%. For other compounds, these differences range from 3 to 10% (for total nitrogen by 32%).

Table 2. Changes in average concentrations of nutrients (mg l^{-1}) in 2009-2010 in the waters of Kopalińskie Lake in the surface, interstitial and near-bottom layer

Layer	Nitrogen	Nitrate	Phosphorus	Phosphates	Ammonia
Surface	1.16	0.98	0.031	0.028	1.31
Near-bottom	1.23	1.03	0.031	0.028	1.33
Interstitial	1.63	1.13	0.074	0.066	1.38

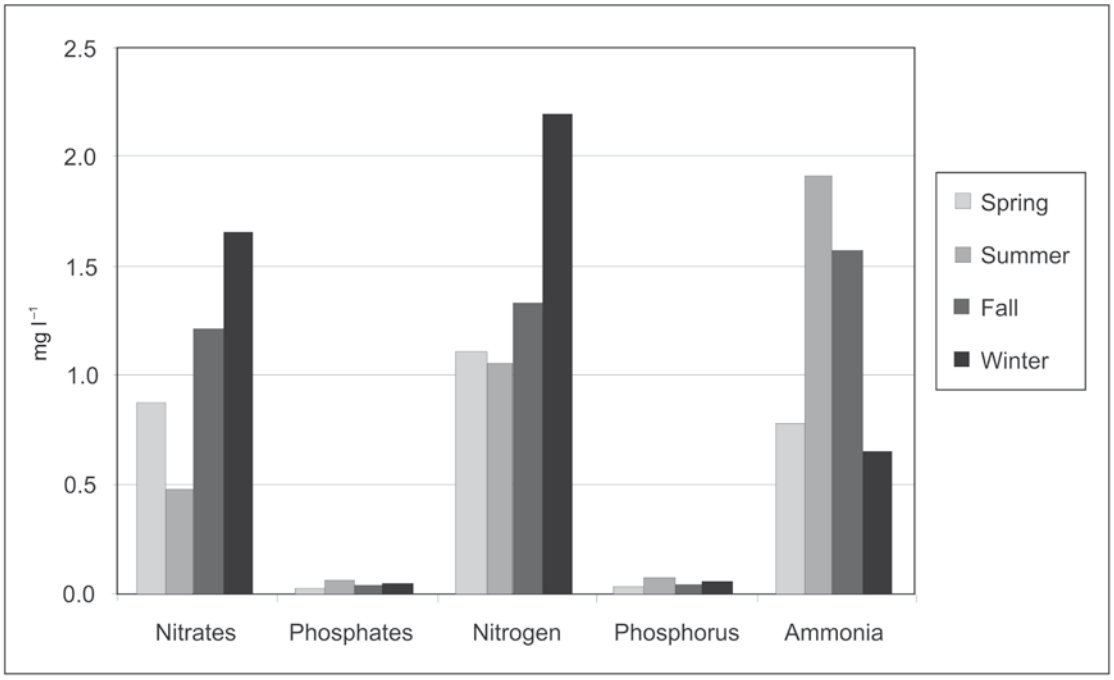


Fig. 9. Seasonal variations in the concentrations of nitrogen and phosphorus in waters of Kopalińskie Lake in 2009-2010

Conclusion

Kopalińskie Lake is classified as a lake located on the Polish coast, formed by anthropogenic activities (peat exploitation). Until now, it had not been the object of hydrological studies. Both the morphometry of the lake basin and hydrographic characteristics of its catchment indicate that it is a water reservoir with the characteristics of a coastal lake, which can be found on the basis of the studies. It is a shallow lake, where the average depth is only 1.6 m and the maximum does not exceed 3.3 m. Isobath distribution is regular. Unlike the other coastal lakes, it has a very significant drop in depth (up to 2 m) in close proximity to the shoreline, which can be explained by the origins of the lake basin. The hydrographic system of the lake catchment is poorly developed. It consists of only a few rivers, which discharge small amounts of water at the level of 0.02-0.1 $m^3 s^{-1}$. The only outlet at that time drained the water at a level from 0.02 to 0.18 $m^3 s^{-1}$. Fluctuations in lake water levels are small, at about 40 cm per year, which differentiates Kopalińskie Lake from the other coastal lakes, where such fluctuations extend to 100 or more centimetres. However, in the literature (Łosińska 1986; Choiński 1991) other examples where such fluctuations were less than 100 cm (Lakes Sarbsko and Modła) can be found. In the case of Kopalińskie Lake the water chemistry classification of this water reservoir as a coastal lake is not so obvious. Its waters are classified as typical fresh waters, where the concentration of chloride in the entire study period did not exceed 10 mg Cl l^{-1}. However, the lack of salinity does not discredit such a lake. On the Polish coast, there are examples of lakes where the salinity is low, and these lakes are still classified in the group of coastal lakes, (Cieśliński 2011). The volume of the concentrations of the biogenic substances indicates that Kopalińskie Lake is strongly influenced by agricultural and urban impacts. Consequently, a significant overgrowing of the lake, particularly visible in the southern part, is observed. Extremely important for the lake is also the phenomenon of re-suspension of bottom sediments, where significant amounts of phosphorus compounds are accumulated.

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