Vol. 3, No. 3, 2018

PRELIMINARY CHARACTERISTICS OF THE WATER CHEMISTRY OF LAKE CZARNE LOCATED IN CATCHMENT OF DRWĘCA RIVER

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Received: 04.09.2018

Abstract. Lake Czarne is an example of a lake that has not been studied until today. The main goal of study is to characterize the hydrochemical properties of Lake Czarne (3.9 ha, 5.1 m) and its trophic condition. The lake waters were characterized by an enough high content of nutrients, up to 0.253 mg P l^{-1} and 5.10 mg N l^{-1}. The high fertility of the lake was exhibited also by the values of BOD5 reaching 12.4 mg O_2 l^{-1} and low transparency – mean value 0.6 m.

Key words: lake, eutrophication, water chemistry, trophic state

1. Introduction

Natural water is a dynamic chemical system containing in its composition a complex group of gases, mineral and organic substances in the form of true solutions, and suspended and colloidal matters as well. The variety and complexity of natural water composition is defined not only by the occurrence of a large number of chemical elements in it, but also by the difference of forms and the values and presence of each of them (Grochowska, Tandyrak 2010; Kubiak, Tórz 2005). Lakes water undergo many complex chemical, physical and biological transformations. Directions of those transformations are determined by water composition, which in turn is shaped by several factors. Among the most important are geological structure and types of land use in a watershed, capacity of the soil sorption complex, weathering and solubility of minerals present in a watershed, atmospheric conditions, mixing of waters varying by their composition, and types of aquatic organisms (Letcher et al. 2002; Schoonover, Lockaby 2006). Lakes with high inflow of minerals and organic compounds from catchment area have an elevated risk for eutrophication. Under natural conditions, this process will be slow and prolonged. However, human civilization has made a significant contribution to the degradation of water and eutrophication acceleration. Lakes adjacent to urban and agricultural areas, in particular, are usually eutrophicated due to receiving municipal sewage and industrial wastewaters and nutrients from leaky septic tanks and agriculture.

Excessive nutrients load contributes to the violation of the existing balance and increases, at least in the initial phase, the intensity of primary production. Clear growth of organic matter usually leads to disturbances of oxygen settings, and sometimes even to complete deoxidation of the environment, due to the consumption of oxygen in the decomposition of organic matter. The appearance of oxygen losses in water over bottom sediments during stagnation periods leads to a reduction of redox potential, and consequently to the release of reduced ions from sediments into the near bottom water. In this situation, bottom sediments cease to be a nutrients trap, and in particular phosphorus – the most important factor causing eutrophication (Grochowska et al 2015).

The next negative phenomena are: change of water colour, smell and taste, low transparency, surface high oxygenation and anaerobic condition in bottom layers of water, appearance of hydrogen sulphides.

The main goal of this paper is to characterize the hydrochemical properties of Lake Czarne and its trophic condition.

2. Material and method

Lake Czarne is located the Warmian-Masurian Voivodeship, in the western part of the Olsztynek commune, in approximately 35 km west of the Olsztyn city, in the Drwęca-Wisła Rivers drainage basin. The geographic coordinates are 53°35′9.69″ N and 20°10′20.64″ E. It is a reservoir with a slightly elongated shape. The lake axis runs from north-west to south-east. The surface area is 3.9 ha and the max. depth is 5.1 m (Fig. 1, Table 1). Detailed morphometric parameters are given in Table 1.

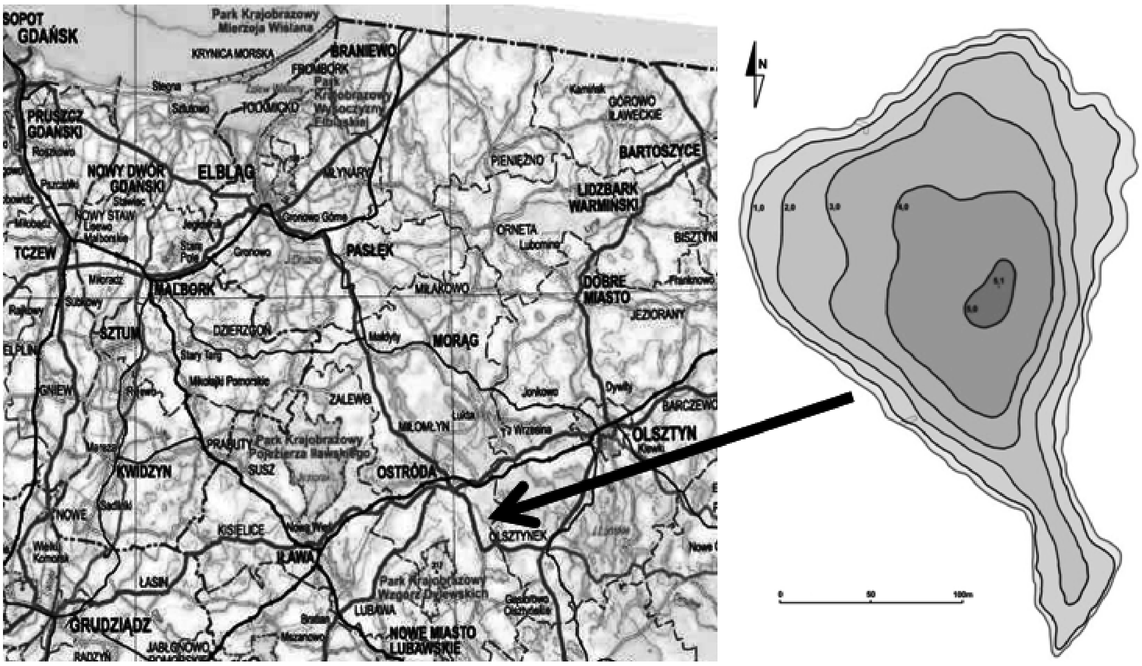

Fig. 1. Bathymetric map and location of the Czarne Lake

Table 1

Detailed morphometric data and lake parameters (Łopata 2017)

Parameter	Value
Surface [ha]	3.9
Volume [th. m^3]	105.2
Maximum depth [m]	5.1
Average depth [m]	2.7
Relative depth	0.026
Maximum length [m]	347.0
Maximum width [m]	216.0
Length of shoreline [m]	935.0
Shoreline development	1.34
Elongation	1.60
Depth index	0.53

The direct basin of Czarne Lake covers an area of 1.08 km^2 and surrounds the reservoir asymmetrically, extending in the major area east of the reservoir. According to available cartographic materials, the lake does not have a surface inflow, however, the configuration of the north-eastern shores favors a periodic (at higher states) inflow of a part of the water from the intermediate catchment.

The nature of the catchment management is – from the point of view of lake water quality – unfavorable, because – according to current research, in a significant percentage (37.1 %) they are arable land, partly only grasslands (3.5 %), as well as areas dispersed housing (0.7 %). On the other hand, the positive aspect is the direct surrounding of the lake with wasteland areas of a seminal nature (8.7 %) and woodlands, which constitute a half of the direct catchment area.

Another aspect of anthropopression, in the immediate vicinity of the lake is a new area of individual development on the north-western outskirts of the lake. In the case of development of lake margins for recreational use (transformation of the natural character of the banks, fertilization of lawns or storage of biomass in connection with the maintenance of premises), a new local source of biogenic pollution should be expected.

The analyses of the physico-chemical properties of the Czarne Lake water were done four times: 03 April, 19 June, 28 August, 24 November 2017. Water for analyses was taken from the deepest site in the lake, determined with the help of the bathymetric chart and gps. Water samples were taken from 1 m depth under the water table and 1 m above the bottom. Simultaneously, temperature and DO were measured at every meter of the water column depth. Water transparency was measured with Secchi disc. Chemical analyses were done in accordance with the methods by Hermanowicz et al. (1999).

3. Study results and discussion

Czarne Lake is shallow (5.1 m) and small reservoir (3.9 ha). However, on the south, west, east and partly on the north it is surrounded by a forest that considerably hinders water access to the water table. Moreover, it is a flow-through reservoir, although that property is weakly evident. Therefore, intensity of the water circulation is determined mostly by the morphometric properties and exposure to wind. The first analysis (April), around three weeks after end of ice cover revealed that in the water layer at the 2 m, water has temperature 13.3 ºC, and below water temperature was 8 ºC. At the mid-June the water column was thermally stratified with a 16.8 ºC temperature difference between the surface and the bottom (Table 2). At the end of August the lake stratified into a 3-m thick epilimnion and a metalimnion with the 8.5 ºC m^{-1} gradient (Table 2). Theoretical water mixing depth in Czarne Lake calculated after Patalas (1960) from the empirical equation $E = 4.4 \sqrt{D}$ is 2.3 m. The study shows that it is 1.3 m higher than the actual thickness of the epilimnion observed at the end of the summer. Taking into account the criteria given by Patalas (1960) Lake Giłwa can be classified as 4rd static degree whereas Olszewski et al. (1978) in which there are only two thermal layers – epilimnion and metalimnion. Lakes belonging to this group can be mixed up to the bottom in an extremely windy year and thus go to group II. A similar situation was noted by Grochowska and Dunalska (2005) in the lake Podkówka in Olsztyn and Grochowska and Tandyrak (2008) in the lake Mały Kopik.

Oxygenation of the lake waters depended on the season. At the beginning of April oxygen content in the surface water layer was high, 14.3 mg O_2 l^{-1} (138.2 % saturation) with 4.5 mg O_2 l^{-1} (37.8 % saturation) near the bottom (Table 2). In the peak of the summer stagnation oxygen conditions deteriorated. High concentrations of the gas were measured only in the 2-m thick layer (from 69.4 to 64.9 % saturation), decreased in the deeper layers and reached the 0.6 mg O_2 dm^{-3} at 3 m depth (Table 2).

Good oxygen conditions at April must have been due to the intensive primary production as confirmed by the high value of BOD_5 (12 m O_2 l^{-1}) (Table 3). Simultaneously, in the near-bottom water layers due to the continuous thermal stratification organic matter decomposed, consuming oxygen and causing its deficits near the bottom. The described distribution of oxygen in the peak of the summer stagnation is illustrated by so-called clinograde curve, typical for the eutrophic lakes (Grochowska et al. 2015).

Table 2

Thermal-oxygen settings found in Czarne Lake during research

Depth [m]	Temperature [ºC]	Oxygen [mg l^{-1}]	% O_2 saturation
03.04.2017			
0	13.3	14.3	138.2
1	13.3	14.3	138.2
2	13.3	14.3	138.2
3	8.6	8.5	72.5
4	8.0	4.5	37.8
19.06.2017			
0	25.3	7.4	92.1
1	20.6	2.9	32.0
2	14.0	0.6	6.0
3	9.4	0.6	5.2
4	8.5	0.6	5.1
28.08.2017			
0	19.4	6.3	69.4
1	19.3	5.9	64.9
2	10.8	5.9	64.9
3	9.8	0.6	5.3
4	8.8	0.6	5.1
24.11.2017			
0	5.7	7.8	63.8
1	5.7	7.8	63.8
2	5.7	7.8	63.8
3	5.7	7.8	63.8
4	5.7	7.8	63.8

One of the indicators of excessive water fertility is the low visibility of Secchi disc. Water transparency in Czarne Lake ranged from 0.2 to 0.9 m and oscillated during the vegetation period around 0.5 m. Supposedly, the excessive biomass of algae is the limiting factor for sunlight penetration in the lake, as shown by the highest amount of chlorophyll a (indicator of the primary production, equal to 39.5 mg m^{-3}) (Table 3).

In the Czarne Lake the limited penetration of sunlight is related to the brown color of water caused by the presence of humic compounds flowing into the reservoir from the forest surroundings.

Czarne Lake is eutrophic reservoir, which trophic state is most probably caused by the enough high nutrients' concentrations which ranged from 2.20 to 5.09 mg N l^{-1} and from 0.214 to 0.440 mg P l^{-1} (Fig. 2). Such values are typical for the high-fertility lakes. The pools of nitrogen and phosphorus were dominated by the organic forms (Table 3), which confirms the high fertility and productivity of the lake (Grochowska, Tandyrak 2007). Following the lake classification by

Zdanowski (1982), referring to the spring content of total P, the described lake can be classified as polytrophic – 5th trophic condition degree. According to Hillbricht-Ilkowska and Wiśniewski (1993), who their classification included water transparency, total P and chlorophyll a, Czarne Lake is the heavily eutrophic reservoir.

Assessment of the production processes in a lake is possible through BOD_5 determination. In the surface waters of the discussed lake, in the vegetation period the values of that parameter were high, approx. 8 mg O_2 l^{-1}, demonstrating the fairly advanced eutrophication.

Table 3

Selected chemical components of Czarne Lake water

Parameter	03.04.2017		19.06.2017		28.08.2017		24.11.2017	
	S	B	S	B	S	B	S	B
Reaction [pH]	7.12	7.12	7.21	6.78	7.25	7.25	7.02	7.02
Conductivity [µScm^{-1}]	205	205	217	215	205	216	166	166
Chloride [mg l^{-1}]	11.5	11.5	11.0	11.0	13.5	13.5	11.0	11.0
BOD_5 [mg O_2 l^{-1}]	12.4	12.4	10.5	10.9	8.2	9.2	-	-
Alkalinity [mval l^{-1}]	1.2	1.2	1.6	1.6	1.3	1.3	0.8	0.8
Total hardness [mval l^{-1}]	2.0	2.0	1.7	1.9	1.9	2.0	1,6	1.6
Calcium [mg l^{-1}]	28.6	28.6	28.6	28.9	30.0	31.0	21.4	21.4
Magnesium [mg l^{-1}]	6.4	6.4	2.8	2.9	4.0	4.3	6.0	6.0
Mineral P [mg l^{-1}]	0.020	0.020	0.055	0.124	0.042	0.242	0.180	0.180
Organic P [mg l^{-1}]	0.194	0.194	0.242	0.241	0.198	0.198	0.073	0.073
Total P [mg l^{-1}]	0.214	0.214	0.297	0.365	0.240	0.440	0.253	0.253
Ammonia [mg l^{-1}]	0.038	0.038	0.042	0.499	0.012	0.612	1.100	1.100
Nitrate N (V) [mg l^{-1}]	0.430	0.430	0.354	0.390	0.125	0.135	0.893	0.893
Organic N [mg l^{-1}]	1.732	1.732	2.294	1.401	2.493	1.493	3.097	3.097
Total N [mg N l^{-1}]	2.200	2.200	2.690	2.290	2.630	2.240	5.09	5.09
Iron [mg l^{-1}]	0.26	0.26	0.24	0.28	0.10	0.15	0.53	0.53
Manganese [mg l^{-1}]	0.68	0.68	0.62	0.76	0.43	0.52	0.88	0.88
Chlorophyll a [µg l^{-1}]	39.5		17.6		13.8		5.6	
Visibility [m]	0.5		0.7		0.9		0.2	

S – surface; B – bottom

Paschalski (1962) who examined the alkalinity of the Mazurian Lakes distinguished three groups. Taking that classification into account and the measured alkalinity (0.8–1.6 mval l^{-1}; Table 3) Czarne Lake can be classified as 1rd alkalinity group, meaning the water is poorly buffered. Total hardness of the Czarne Lake water ranged from 1.6 to 2.0 mval l^{-1} (80.1–100.1 mg $CaCO_3$l^{-1}) (Table 3). In accordance with the classification by Dojlido (2001), the water in Czarne Lake is medium soft. The hardness was mainly determined by the calcium content varying from 21.4 to 31.0 mg Ca l^{-1} (Table 3). The woody character of the watershed caused that concentrations of calcium measured in the lake were low (Grochowska, Tandyrak 2009). Magnesium occurs in much smaller quantities than calcium (Chełmicki 2002). In surface water, the content of this element is 3 – 4 times lower than calcium (Orzepowski, Pulikowski 2008). This is confirmed by the results obtained during the study of the Czarne Lake, where the amount of magnesium was about 3 to over 10 times lower than calcium. Koc et al. (2008) argue that the lakes formed on the post-glacial land, ie such as the analyzed reservoir, are poor in magnesium.

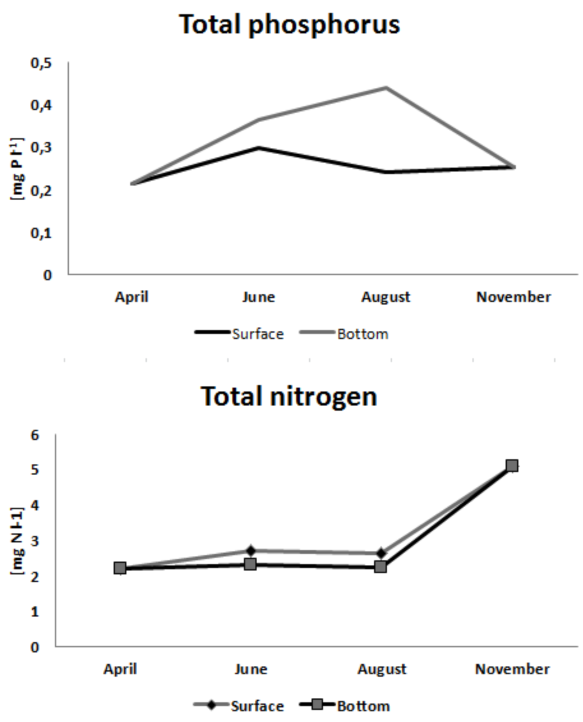

Fig. 2. Contents of total phosphorus and total nitrogen in water of Czarne Lake

Electrolytic conductivity indicates the degree of the water pollution with mineral compounds. Marszelewski (2005) analyzed the electrolytic conductivity of the North Poland lakes and selected a group of eutrophic lakes in which the values were from 200 to 400 µS cm^{-1}. Conductivity of the Czarne Lake water ranged from 166 to 217 µS cm^{-1} (Table 3) thus fitted in the range typical for the lakes of a moderate fertility.

Chloride ions dissolved in the water come from the ground or with contaminants. According to the classification by Olszewski and Paschalski (1959) water receiving no sewage contains to 15 mg Cl l^{-1}. Due to the forest surroundings of the Czarne Lake and lack of point sources of pollution the content of chlorides in the water was in ranged 11.0 13.5 mg Cl l^{-1} (Table 3).

The occurrence of iron in lake water depends on the content of organic substances, carbon dioxide, aerobic conditions, pH of water and the activity of microorganisms (Zaw, Chiswell 1999). In the upper layers of eutrophic lakes, where water oxygenation, high pH and significant amounts of organic matter are observed, iron reaches low concentrations, while in the deep zone, where anaerobic conditions prevail, high concentrations of its divalent form can be detected. In the entire mass of the Czarne Lake water, the amount of iron was not very high and ranged from 0.10 to 0.53 mg Fe l^{-1}. The source of iron in the analyzed basin is probably forest areas that cover over 50 % of the direct catchment. Bojar (2003) reports that iron can occur in large quantities in mid-forest streams, wetland soils and on peat bogs, because it forms bonds with humic substances.

The manganese compounds in water are more stable than iron compounds and are more difficult to hydrolyse (Korzeniowski 1986). They can come from the leaching of various types of rocks and soils, moreover from plant and animal residues (Dojlido 2001). The manganese content in surface water usually does not exceed 1 mg Mn l-1. Transformations of this element in water, like iron, depend on aerobic conditions and reaction. According to Chełmicki (2002), under similar conditions, there are about ten times smaller concentrations of manganese in relation to iron. In Czarne Lake water no such dependence was noted, as the amounts of manganese ranged from 0.43 to 0.88 mg Mn l^{-1}, and thus were higher than iron (Table 3). This situation may be related to the lake's environment, over 30 % occupied by intensively cultivated arable land. According to Dojlido (2001), manganese and its compounds are used for the production of plant protection chemicals and fertilizers.

Conclusions

1. Czarne Lake is the 4rd static degree reservoir (Patalas 1960).
2. The summer oxygen distribution in the water column displays the clinograde curve, which indicates high fertility of the lake.
3. Czarne Lake is nutrient-rich. Concentrations of the nutrients are to 0.440 mg P l^{-1} and 5.09 mg N l^{-1}
4. According to the criteria given be Zdanowski (1982) Czarne Lake is polytrophic – 5th trophic status degree whereas the guidelines given by Hillbricht-Ilkowska and Wiśniewski classify it as heavily eutrophic.
5. The Czarne Lake water is poorly buffered, medium soft, and considerably poorly in calcium.
6. The moderate fertility of Czarne Lake waters is confirmed by the electrolytic conductivity reaching 217 µS cm^{-1}.

References

[1] Bojar W., 2003. Seasonal changes in the content of heavy metals in the waters of selected lakes of the Łęczyńsko – Włodawskie Lakeland. Acta Agrophysica 1(3), 377–384.

[2] Chełmicki W., 2002. Water, resources, degradation, protection. Ed. PWN, Warsaw, 17–31.

[3] Dojlido J., 2001. Surface water chemistry. Ed. Ekonomia i Środowisko, Białystok.

[4] Grochowska J., J. Dunalska, 2005. Trophic condition of Lake Podkówka and the basin role in the lake's eutrophication. Limnological Review, 5: 93–99.

[5] Grochowska J., R. Brzozowska, M. Łopata, J. Dunalska, 2015. Influence of restoration methods on longevity of changes in the thermal and oxygen dynamics in degraded lake. Oceanological and Hydrobiological Studies, 44(1): 18 – 27, DOI: 1515/ohs-2015-0003.

[6] Grochowska J., R. Tandyrak 2008. Preliminary trophic characteristics of Lake Mały Kopik near Olsztyn and its drainage basin as the nutrients supplier. Journal of Elementology, 13(1): 57–67.

[7] Grochowska J., R. Tandyrak 2010. Water chemistry of Lake Giłwa. Journal of Elementology, 15(1): 19–29.

[8] Grochowska J., R. Tandyrak, 2009. The influence of the use of land on the content of calcium, magnesium, iron and manganese in water, exemplified in three lakes in the Olsztyn vicinity, Limnological Review, 9(1): 9–16.

[9] Grochowska J., Tandyrak R., 2007. Nitrogen and phosphorus compounds in Lake Pluszne. Archives of Environmental Protection. 33(1): 59–66.

[10] Hermanowicz W., Dożańska W., Dojlido J., Koziorowski B., Zerbe J., 1999. Physical – chemical examination of water and sewage. Ed. Arkady, Warsaw.

[11] Hillbricht – Ilkowska A., Wiśniewski R. J., 1993. Trophic differentiation of lakes the Suwałki

Landscape Park (North – Eastern Poland) and its Buffer Zone – Present State, Changes Over Years. Position in trophic classification of lakes. Ekologia Polska, 41(1 – 2): 195–219.

[12] Koc J., Rafałowska M., Skwierawski A., 2008. Changes in Magnesium concentrations and load in runoff water from nitrate vulnerable zones. Journal of Elementology, 13(4), s. 559–570.

[13] Korzeniewski K., 1986. Hydrochemistry. WSP, Słupsk.

[14] Kubiak J., Tórz A., 2005. Eutrophication. Basic problems of lake water protection in Western Pomerania. Słupskie Prace Biologiczne 2: 17–36.

[15] Letcher R. A., Jakeman A. J., Calfas M., Linforth S., Baginska B., Lawrence I., 2002. A comparison of catchment water quality models and direct estimation techniques. Environmental Modelling & Software 17: 77–85.

[16] Łopata, 2017. Bathymetric map and elaboration of morphometric data of the Czarne Lake. Olsztyn.

[17] Marszelewski W., 2005. Changes of abiotic conditions in the lakes of north-eastern Poland. Habilitation dissertation. Ed. UMK, Toruń.

[18] Olszewski P., Paschalski J., 1959. Preliminary limnological characterization of some lakes of the Masurian Lake District, Zesz. Nauk. WSR Olsztyn, 4: 1–109.

[19] Olszewski P., Tadajewski A., Lossow K., Więcławski F., 1978. Preliminary limnological characterization of some lakes of the Masurian Lake District. Zesz. Nauk. ART. Olszt., 7: 3–81.

[20] Orzepowski W., Pulikowski K., 2008. Magnesium, Calcium, Potassium, and Sodium content in groundwater and surface water in arable lands in the commune Kąty Wrocławskie, Journal of Elementology, 13(4), s. 605–614.

[21] Paschalski J., 1962. Summer stratification of carbonate in Masurian lakes. Zesz. Nauk. WSR, Olsztyn, 14(242), s. 405–423.

[22] Patalas K., 1960. Water mixing as a factor determining the intensity of the matter's circulation in morphologically different lakes of the area around Węgorzewo. Rocz. Nauk Rol., 77(B – 1): 223–242.

[23] Schoonover J. E., Lockaby B., 2006. Land cover impacts on stream nutrients and fecal coli form in the Lower Piedmont of West Georgia. Journal of Hydrology 331: 371–382.

[24] Zaw M., B. Chiswell, 1999. Iron and manganese dynamics in lake water. Water Research 33 (8), s.: 1900–1910.

[25] Zdanowski B., 1982. Variability of nitrogen and phosphorus contents and lake eutrophication. Polskie Archiwum Hydrobiologii, 29(3-4): 541–597.