Journal of Elementology ISSN 1644-2296

Tandyrak R., Grochowska J., Łopata M. 2017. *Hydrochemical parameters and trophic state of an urban lake used for recreation*. J. Elem., 22(4): 1347-1358
DOI: 10.5601/jelem.2017.22.1.1071

ORIGINAL PAPER

HYDROCHEMICAL PARAMETERS AND TROPHIC STATE OF AN URBAN LAKE USED FOR RECREATION*

Renata Tandyrak, Jolanta Grochowska, Michał Łopata

Department of Water Protection Engineering
University of Warmia and Mazury in Olsztyn, Poland

Abstract

Every lake located in an urban area or in the vicinity of a town is a unique element of the landscape. However, lakes situated in cities are particularly endangered as they have a role of receiving water for municipal, industrial and precipitation wastes. The load of nutrients introduced with sewage is so high that it disturbs the biological balance and disrupts biogeochemical processes in an ecosystem. The object of the study was an urban Lake Sajmino (21.6 ha, max. depth 7.8 m) used for recreation. Its catchment is smaller than the topographic catchment area because some of the precipitation water is redirected outside by a storm water drainage system. The lake is fed by 3 permanent inflows (I-III). The goal of the study was to find correlations between the hydrochemical and biological parameters of the lake water and the quality of water supplied by the inflows. Simultaneously, an attempt was made to identify the hazards, in order to undertake actions in the near future preventing deterioration of the lake's trophic state. The amounts of pollutants flowing into the lake from various sources exceeded the acceptable levels, therefore leading to an increase in its trophy, exhibited by algal blooms and limitation in the transparency of the lake water expressed as Secchi disc visibility. A significant ($p \leq 0.05$) inverse correlation between Chl a and SD (r = –0.755) was found for the lake water, and between the Chl a of the lake and the pollutants of the inflows: N_{NH4} (I), r = 0.786, N_{NO2} (I), r = 0.731, N_{NO2} (II), r = 0.881, suspension (III), r = –0.719. TSI indicates that the eutrophic character of the lake is still unsettled. TSI (TP) > TSI (TN) > TSI (SD) > TSI (Chl *a*). The SD value (2.2÷3.55 m) may be caused by dissolved organic matter, the suspension or the water's colour. Phytoplankton (Chl $a \leq 4.840$ µg dm^{-3}) could be limited by nitrogen, zooplankton feeding or toxic compounds.

Keywords: Secchi disc visibility, water pollution, chlorophyll *a*, TSI.

Renata Tandyrak, PhD, Eng., Assistant Professor, Chair of Environmental Protection Engineering, University of Warmia and Mazury, Prawocheńskiego 1, 10-957 Olsztyn, Poland, e-mail: renatat@uwm.edu.pl
* This study was funded by the Ministry of Science and Higher Education in Poland (problem group No 38 UPB titled "Inland water ecosystems, its protection and restoration of lakes" Subject No 0806.0802 "Improvement of the water reservoirs protection and restoration methods").

INTRODUCTION

Every lake located in an urban area or in the vicinity of a town is a special and unique element of the landscape. It shapes the climate, supplies the town with water, and plays an important role in the recreation and active leisure of the town's inhabitants. The availability of the lake's shoreline, allowing for such activities as sunbathing on the beach, bathing, angling or walking, is of no less importance. Lush vegetation impedes access to the lake. On the other hand, it acts as a buffer zone for the inflowing surface pollutants (Cappiella, Schueler 2001). This zone is important, as lakes are very susceptible to the impact of increasing pollution loads, both organic and mineral, introduced from catchment areas that are heavily transformed anthropogenically (Schueler, Simpson 2001, Dunalska 2011). In practice, this is exhibited by the intensification of primary production and deterioration of aesthetic and hygienic conditions (Nawrocka, Kobos 2011), an increase in difficulties and costs in the treatment of the water being derived, and in a further perspective – by the elimination of the reservoir from fishing and recreational use. As an important element of the urban landscape, lakes are subject to constant "monitoring" by inhabitants – their users (Coles et al. 2013). From the user's point of view, the purity of the water in the lake is important, meaning its high transparency, no algae blooms and lack of odor. Such features are characteristic for reservoirs with a low trophy. The protection of lakes consists in a considerable limitation or elimination of the flows of nutrients and organic matter loads into water, and therefore control of the hydrochemical parameters of the water of the lake and its inflows becomes necessary. It is these parameters that constitute the basis for the formation of biological and sanitary conditions. Coherent, deliberate actions undertaken sufficiently early may eliminate the necessity of costly reclamation in future.

The goal of the work was to find connections between the hydrochemical and biological parameters of an urban lake's water and the quality of water supplied by the inflows from the lake's catchment area which was transformed by human activities. Simultaneously, we strove to identify the hazards, in order to undertake in the near future actions preventing deterioration of the trophic state, which is important for the aesthetics of the urban landscape, and from the point of view of using the lake for recreational and economic purposes.

MATERIAL AND METHODS

Lake Sajmino (max. depth 7.8 m, area 21.6 ha) lies in north-eastern Poland, in the western part of the Mazury Lake District, on the outskirts of a small town (population: 33,000) – Figure 1. The lake is fed by 3 permanent

Fig. 1. Research area

surface inflows (I – drains the Kajkowo (flow between 1.3 - 4.0 l s^{-1}) Tunnel Valley, II – drains the area of a housing estate in suburban Kajkowo (flow between 1.6 - 8.6 l s^{-1}), III – drains the area of a former military range (flow between 0.2 - 0.7 l s^{-1}) – Figure 1.

The studies were carried out during the plant growing period of 2013, from May to October. For full chemical analysis, water was sampled in the deepest part of the lake with a 3.5-liter Ruttner sampler, from the depths of 1 and 7 m above the bottom (6.8 m). The thermal-oxygen profiles and electrolytic conductance were determined in the full vertical section of the lake. Also, the Secchi disc visibility (SD) was determined.

Oxygen (DO) and temperature were determined with an optical oxygen probe ProOdo (YSI, USA). Electrolytic conductivity was measured with a MultiLine probe. Colorimetric measurements included: total phosphorus (TP) and phosphate (P_{PO_4}), nitrate (V) nitrogen (N_{NO_3}), nitrate (III) nitrogen (N_{NO_2}), taken with a NANOCOLOR UV/VIS spectrophotometer (MACHEREY – NAGEL GmbH & Co, Switzerland). The amounts of ammonia (N_{NH_4}) were determined on a Merck SQ118 spectrophotometer (Germany), while Kjeldahl nitrogen (N_{kj}) (after mineralization with H_2SO_4 and $CuSO_4$) was determined by the distillation method with 0.1 M HCl. Organic nitrogen ($N_{org.}$) was calculated as the difference between N_{kj} and N_{NH4}. TN was calculated as the sum of N_{kj}, N_{NO_3}, and N_{NO_2}. TP (after mineralization with H_2SO_4 and $K_2S_2O_8$) and P_{PO4} were determined using ammonium molybdate (VI) and $SnCl_2$ (λ = 690 nm). Organic phosphorus ($P_{org.}$) was calculated as the difference between TP and PO_4. BOD was determined by the dilution method. Chlorides (Cl^-)

were determined by titration with $AgNO_3$. Chlorophyll *a* (Chl *a*) was analyzed by colorimetry, after concentration on a Whatman GF/C glass-fiber filter and extraction with acetone (650 and 750 nm). The analyses were complient with the common hydrochemical research methodology (HERMANOWICZ et al. 1999). The main assessment indicators of a lake's trophic status are concentrations of nitrogen and phosphorus, oxygen, water transparency and the content of chlorophyll *a*. In addition, indicators of biotic and abiotic components are applied.

One of the most popular indicators is the Carlson Trophic State Index – TSI (CARLSON 1977, KRATZER, BREZONIK 1981), which consists of three parameters determining numerical values for the content of chlorophyll a, total phosphorus and Secchi disc visibility. The trophic state was determined on the basis of the TSI using a logarithmic transformation of SD, the concentration of Chl *a*, TP (60-14.41 ln(SD), 9.81 ln(Chl *a*) + 30.6, 14.42 ln(TP) + 4.15) (CARLSON 1977), as well as TN concentration (54.45 + 14.43 ln(TN)) (KRATZER, BREZONIK 1981). Index values are in the range from 0 to 100. The higher the value, the higher the trophic level reached by the assessed water body.

The flow rate of water in the inflows to Lake Sajmino was measured using a VALEPORT 801 induction flowmeter (801 model, Valeport Ltd United Kingdom). Simultaneously, water was collected from the inflows, and its physico-chemical parameters were investigated according to the methodology mentioned above.

The statistical analysis consisted of calculations of average values and standard deviation for the studied hydrochemical parameters of the water of the lake and its inflows. The results showed distribution different from normal one, and a non-parametric version of classical one-way ANOVA was used for evaluation. The correlations between the physico-chemical parameters in the water samples from the lake and inflows I, II, and III were determined by the Spearman's non-parametric rank correlation test ($p \leq 0.05$). Statistical analyses were performed using Statistica 10.0 software (StatSoft, Poland).

RESULTS

The basic physico-chemical parameters (average values and standard deviation) of water of Lake Sajmino and its inflows are collected in Table 1. The Spearman's correlation coefficients for the physico-chemical parameters of the lake, including the significant ones (at the level of $p \leq 0.05$) for the lake and its inflows, are shown in Table 2. The SD of Lake Sajmino water was typical for eutrophic lakes, and oscillated between 2.2 and 3.5 m (Figure 2). This reflected the level of the primary production of phytoplankton determined by the Chl *a* concentration, reaching maximally 4.840 μg dm^{-3} in the lake studied. There was a significant inverse statistical dependence between these parameters ($r = -0.754$).

Table 1

Mean and standard deviation (±SD) values of physico-chemical parameters in Lake Sajmino and samples collected from inflows I – III

Parameter (mg dm^{-3})	Samples from the lake n = 16		Inflow to the lake n = 24			Differences (p) between inflows
	surface layer	near bottom layer	I	II	III	
DO	9.4±1.02	4.2±2.8	8.2±2.0	10.6±0.7	10.1±1.0	0.025
TP	0.122±0.035	0.156±0.063	0.626±0.286	0.495±0.306	0.273±0.375	0.001
P_{PO_4}	0.022±0.013	0.042±0.013	0.337±0.180	0.308±0.139	0.101±0.111	0.005
$P_{org.}$	0.100±0.037	0.113±0.053	0.298±0.170	0.187±0.192	0.172±0.271	0.001
N_{NH_4}	0.045±0.083	0.125±0.044	0.243±0.190	0.110±0.113	0.138±0.151	0.227
N_{NO_2}	0.003±0.006	0.004±0.006	0.041±0.043	0.03±0.02	0.008±0.009	0.299
N_{NO_3}	0.102±0.034	0.168±0.032	1.040±0.760	5.90±1.36	1.085±1.231	0.001
$N_{org.}$	0.114±0.043	1.234±0.528	2.203±0.913	1.51±1.37	1.119±0.792	0,003
TN	1.405±0.224	1.63±0.300	3.488±1.031	7.50±1.200	2.349±1.868	0.000
Cl^-	41.0 ±2.1	41.3±1.6	52±2,5	67±3,8	46±2,7	0.001
BOD*	2.4±1.8	2.8±1.1	4.2±2.6	4.4±2.8	3.0±3.1	0.040
Reaction (pH)	8.45±0.219	7.91±0.361	7.69±0.089	8.16±0.287	8.16±0.149	0.002
Conductivity (μS l^{-1})	415±20	437±15	546±184	704±164	486±121	0.281

Table 2

Statistic estimation by the Spearman's correlation between physicochemical parameters in samples collected from Lake Sajmino and its inflows
(***** – statistically significant differences at $p < 0.05$)

				The lake								
		SD	Chl *a*	seston	P_{PO_4}	TP	N_{NO_3}	TN	TN/TP	Cond.	Cl	BOD
The lake	SD	1.000	-0.754*	-0.347	-0.355	-0.479	-0.347	-0.395	0.455	0.060	-0.360	0.271
	Chl *a*		1.000	0.405	0.228	0.429	0.571	0.238	-0.500	-0.476	0.284	-0.299
	P_{PO_4}			1.000	1.000	0.060	-0.144	0.743*	0.431	0.419	0.653	-0.482
	Seston				-0.467	0.571	0.524	-0.191	-0.810*	-0.310	-0.272	0.275
	TP					1.000	0.071	0.619	-0,714*	0.048	0.593	-0.443
	N_{NO_3}						1.000	-0.310	-0.143	-0.762*	-0.334	0.231
	TN							1.000	0.048	0.405	0.964*	0.802*
	TN/TP								0.191		-0.074	0.084
	Conductivity									1.000	0.272	0.036
	Cl										1.000	-0.895*
Inflow I	N_{NH_4}		0.786*									
	N_{NO_2}		0,731*			0.778*						
	TN						0.881*			-0.857*		
	P_{PO_4}						0.929*					
	TP						0.738*					
	Conductivity						0.8333*					
Inflow II	N_{NO_2}		0.881*									
	P_{PO_4}						0.905*			-0.786*		
	TP						0.881*			-0.738*		
	Conductivity						0.762*			0.714*		
Inflow III	N_{NH_4}				0.842*							
	N_{NO_2}		0.807*									
	N_{NO_3}						0.731*				-0.845*	0.723*
	TN						0.731*					
	P_{PO_4}						0.731*	0.850*			0.845*	0.723*
	TP						0.970*					
	Conductivity									0.814*		
	Suspension		-0,719*				-0.826*					

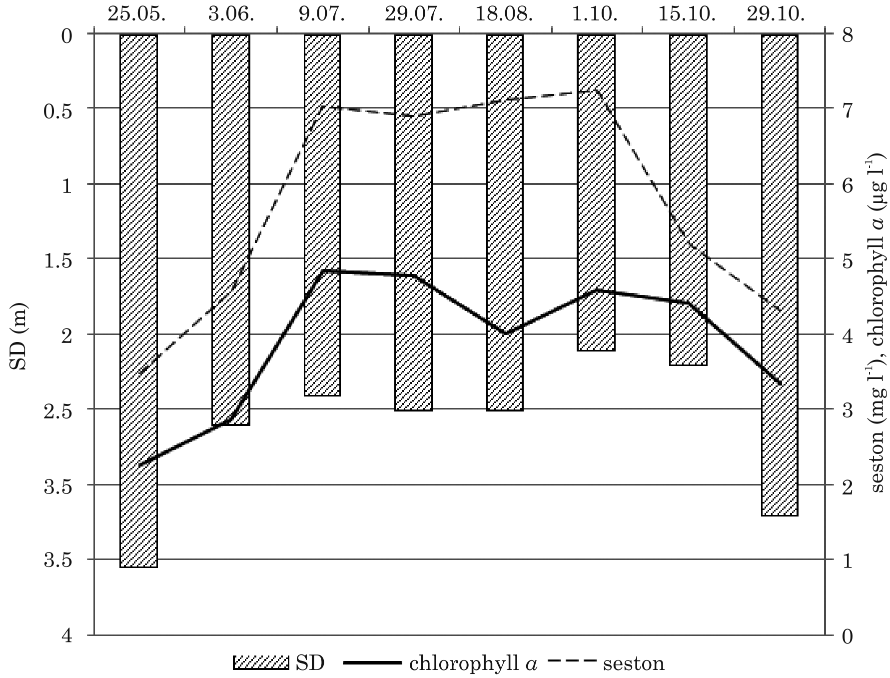

Fig. 2. SD and concentration of chlorophyll *a* (Chl *a*) and seston in Lake Sajmino

Primary production depended on the availability of biogenic elements. During the investigations, concentrations of nutrients were found not to be very high, oscillating between 1.030÷1.740 and 1.040÷1.960 mg N dm^{-3} for TN, and between 0.078÷1.173 and 0.086÷0.266 mg P dm^{-3} in the case of TP, in the surface and benthic compartments of the lake water, respectively. In both water layers, the organic form prevailed in the total amount of these elements, constituting 82÷94% $N_{org.}$ and 60÷88% $P_{org.}$ respectively.

In the surface layer, the ratio of nitrogen to phosphorus ($8.3 < N/P < 14.2$) had the lowest value in August, at the poorest visibility (Figure 3). A significant statistical dependence between the N/P ratio and the seston amount in the lake water was found (r = –0.809). The mutual relationships between SD and Chl *a*, TN, DN concentrations, making up the total TSI, indicate the eutrophic character of the lake (Table 2).

The TN concentration in the surface layer of the lake water was closely related to P_{PO_4} (r = 0.743), BOD (r = –0.802 and Cl^- (r = 0.964). The BOD for this water layer was in the range of 0.8 to 5.2 mg O_2 dm^{-3} while varying from 1.6 to 4.0 mg O_2 dm^{-3} in the benthic compartment.

The Spearman rank method showed that the values of the parameters measured in the surface layer of the lake water were significantly correlated with the parameters of the water of the inflows (Table 2). The Chl a concentration in the lake water depended primarily on N_{NO_2} introduced by the

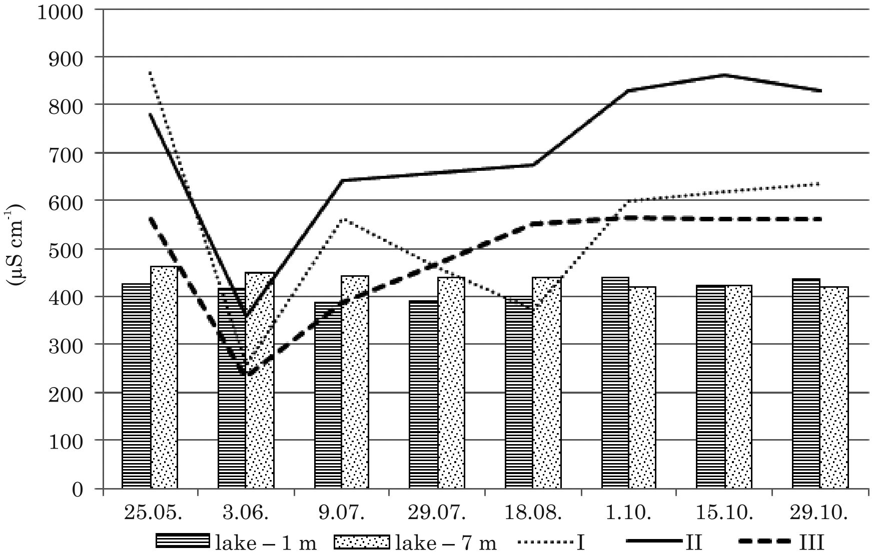

Fig. 3. Electrolytic conductance of surface water of the lake and its inflows (I-III)

inflows (r = I: 0.730; II: 0.881; III: 0.807), as well as on N_{NH_4} in inflow I (r = 0.786) and suspension carried by inflow III (r = –0.720).

The values of most of the chemical parameters determined in inflowing water varied statistically (Table 1). This was above all manifested by TN and N_{NO3} concentrations, and TP and P_{PO_4} concentrations. The highest TN concentrations (7.500±1.20 mg dm^{-3}) were found in inflow II, and the element occurred mostly (55÷93%) as N_{NO_3}. The highest TP concentrations occurred in inflow I (0.626±0.286 mg P dm^{-3}). The contribution of the mineral form into TP reached 30÷84%, which was lower than in the case of minerl N in TN.

The water of inflow II was characterized by the highest electrolytic conductance (Figure 3, Table 1). The values were correlated with TN (r = 0.857). Also, the highest Cl^- concentrations, reaching 70 mg dm^{-3}, were observed in inflow II. The amount of suspension in water of the streams changed very significantly. This was confirmed by the value of standard deviation exceeding the mean values (Table 1). The extreme concentration of this component, reaching 287.5 mg dm^{-3} in inflow II, was observed after heavy rainfall.

The highest load of nutrients was contributed by inflow I (38% TN and 43% TP). Taking into account the nutrients fed from the zone's zonal sources, it was estimated that in total, 112.0 kg P and 1589.7 kg TN flew into the lake annually, including 8.5 kg TP and 49.8 kg TN as a result of leisure activities (bathing and angler's bait) – Figure 4.

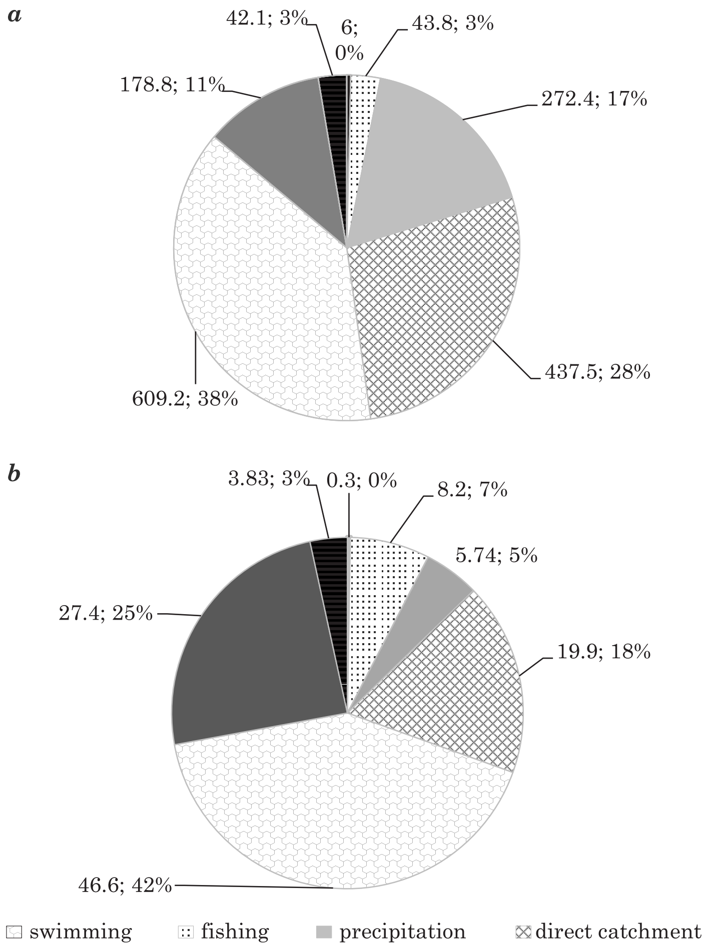

Fig. 4. External load to Lake Sajmino by (*a*) TN and (*b*) TP (kg/year)

DISCUSSION

Because of the diversified management of its anthropogenically transformed catchment area, Lake Sajmino is a recipient of pollutants originating from various sources. Although limiting the surface runoff of rainwater by its redirection outside the topographic catchment area is probably beneficial for the lake's protection (Ejankowski, Lenard 2014), it was found that the loads imported to the lake were found to exceed the values considered as permissible ones (Vollenweider 1976). Taking into account the actual area flow and recreational use of the lake, acceptable levels were exceeded by approx. four -fold for TP and 3.8-fold for TN. The highest nutrient load was carried by inflow I (Figure 4).

Extremely high concentrations of nitrates were found (exceeding 7.000 mg N dm^{-3}) in water of inflow II. Values of electrolytic conductance reached 864 μS cm^{-1}. This water also carried significant amounts of suspension, reaching 287.5 mg dm^{-3} after heavy rainfall. This indicates possible wastewater pollution, probably resulting from an overflowing sewage system or septic reservoir leakage. (GROCHOWSKA, TANDYRAK 2010). The significant correlation between TN in the lake and P_{PO_4} (0.743), BOD (–0.802) and Cl^- (0.964) in lake water may be interpreted in a similar way.

Our studies showed that pollution carried directly by the watercourses contributed to the intensification of primary production. For most partial indices, the value of the TSI index indicated the eutrophic character of the lake.

In the discussed case: TSI (TP – 72.7) > TSI (TN – 57.6) > TSI (SD – 44.7) > TSI (Chl *a* – 42.8). The dependencies between the values of these indices suggest (KRATZER, BREZONIK 1981, BROWN, SIMPSON 1998, SAGHI et al. 2014, NAPIÓRKOWSKA-KRZEBIETKE et al. 2016) that the low transparency of water may be caused by a high concentration of dissolved organic matter, turbidity (resulting from the presence of suspension limiting the access of light), or the water's own colour. Simultaneously, phytoplankton probably significantly affected the visibility of the water, although its occurrence might be limited by many factors, for instance, limitation by nitrogen, zooplankton feeding, or toxic compounds.

SD is directly connected with primary production, and thus with the fertility of the lake and the availability of mineral forms of nitrogen and phosphorus, necessary for this production. The N/P ratio determined the occurrence of algal blooms. If the ratio has a low value, particularly noxious blue-green algae can occur in the water (XIE et al. 2003, NÖGES et al. 2007), having a negative effect on the aesthetic value of the lake and the smell of its water. With an N/P value as in the discussed case, blue-green algae are likely to develop. Their presence is always undesirable, because they release toxic metabolites into the water (NASELLI-FLORES et al. 2007, BLÁHA et al. 2009, GIDDINGS et al. 2102) frequently preventing the lake from performing the function of a bathing area (OBERHOLSTER et al. 2006).

However, one should note the high partial TSI (SD) and the fact that the benthic compartment of the lake water contained oxygen (43÷17% O_2) in the whole plant growing period, which is a characteristic feature of moderately trophic lakes. This is confirmed by the content of Chl *a* ≤ 4.84 μg dm^{-3} characteristic for mesotrophy (KASPRZAK et al. 2008), and by the amount of dry mass of seston (0.8÷3.1 mg dm^{-3}) – Figure 2.

The degree of the lake's eutrophication and the intensity of mixing its water were connected with the oxygen content in the epilimnion. The water was hyperoxygenated during the study (from 122.6 to 96.6% O_2). On the other hand, no oxygen depletion in the benthic compartment during the summer stagnation was observed, and therefore there was no danger of internal feeding of the water. In the vertical oxygen distribution, a deficiency of the gas was evident, which is characteristic for mesotrophy. However, a positive heterograde, characteristic for this type of waster bodies (Grochowska et al. 2006), was not observed in the metalimnion.

Electrolytic conductivity indicates the degree of the water pollution with mineral compounds. Marszelewski (2005) analysed the electrolytic conductivity of lakes in northern Poland and distinguished a group of eutrophic lakes where the EC values were from 200 to 400 μS cm^{-1}. Conductivity of the water in Lake Sajmino ranged from 388 to 462 μS cm^{-1} (Figure 3), and in the inflows it varied between 231 and 864 μS cm^{-1} (Figure 3). Marszelewski (2005) reports that electrolytic conductivity along the water column in heavily eutrophied lakes in summer differs, with the values increasing toward the bottom. In Lake Sajmino, the conductivity increased with the depth (Figure 3). High electrolytic conductivity of this lake's water is related to the input of polluted inflows water.

All this may indicate that the eutrophic state of Lake Sajmino is still unsettled, intermediate between meso- and eutrophy (Kuehl, Troelstrup 2013), but unless action is taken within the lake's catchment area, it will probably stabilize as the so-called turbid state. The transfer of a lake system from the so-called pure-water state to the turbid state occurs rapidly, while the reverse process is very slow (Hargeby et al. 2007, Tátrai et al. 2009), and only a dramatic change in the environmental conditions may yield a chance to accelerate it. Therefore, knowing the potential hazards, one may strive to enforce proper protection methods and undertake adequate action at the stage when the trophy of the lake has not advanced to the eutrophic state permanently.

REFERENCES

Bláha L., Babica P., Maršálek B. 2009. *Toxins produced in cyanobacterial water blooms - toxicity and risks.* Interdisciplinary toxicology, 2(2): 36-41. DOI: 10.2478/v10102-009-0006-2.

Brown T., Simpson J. 1998. *Managing phosphorus inputs to urban lakes.* Urban Lakes Management, 771-781. DOI: 10.2478/v10102-009-0006-2

Cappiella K., Schueler T. 2001. *Crafting a lake protection ordinance.* Waterhed Protection Techniques, 3(4): 751-768.

Carlson R.E. 1977. *A Trophic State Index for lakes*. Limnol. Oceanogr., 22(2): 361-369.

Coles R., Millman Z., Flannigan J. 2013. *Urban landscapes - everyday environmental encounters, their meaning and importance for the individual.* Urban Ecosyst., 16(4): 819-839.

Dunalska J.A. 2011. *Impact of morphometric and catchment variables on summer organic carbon richness in deep temperate lakes. Knowl. Manag. Aquatic Ecosyst.*, 403, 03. DOI: 10.1051/kmae/2011043

Ejankowski W., Lenard T. 2014. *Trophic state of a shallow lake with reduced inflow of surface water.* Arch. Environ. Protect., 40(3): 3-11.

Giddings M., Aranda-Rodriguez R., Yasvinski G., Watson S.B., Zurawell R. 2012. *Canada: Cyanobacterial toxins: drinking and recreational water quality guidelines.* In: *Current approaches to Cyanotoxin risk assessment, risk management and regulations in different countries.* http://www.uba.de/uba-info-medien-e/4390.html

Grochowska J., Tandyrak R. 2010. *Water chemistry of Lake Giłwa*. J. Elem., 15(1): 89-99.

Grochowska J., Teodorowicz M., Tandyrak R. 2006. *Temperature and dissolved oxygen characteristics of the lakes in the upper Pasłęka River catchment*. Pol. J. Natur. Sci., 20(1): 291-305.

Hargeby A., Blindow I., Andersson G. 2007. *Long-term Patterns of Shifts between Clear and Turbid States in Lake Krankesjön and Lake Tåkern*. Ecosystems, 10: 28-35. DOI: 10.1007/s10021-006-9008-5

Hermanowicz W., Dojlido J., Dożańska W., Koziorowski B., Zerbe J. 1999. *Physicochemical methods of water and wastewater examination*. Arkady, Warszawa, pp 556. (in Polish)

Kasprzak P., Padisak J., Koschel R., Krienitz L., Gervais F. 2008. *Chlorophyll a concentration across a trophic gradient of lakes: An estimator of phytoplankton biomass?* Limnologica--Ecology and Management of Inland Water, 38(3): 327-338. DOI: 10.1016/j.limno.2008.07.002

Kratzer C.R., Brezonik P.L. 1981. *A Carlson-type trophic state index for nitrogen in Florida lakes,* Water Res. Bull., 17(4): 713-715.

Kuehl L.C., Troelstrup Jr, N.H. 2013. *Relationships between net primary production, water transparency, chlorophyll a, and total phosphorus in Oak Lake, Brookings county, South Dakota*. Proc. of the South Dakota Academy of Science, 92: 67-78.

Marszelewski W. 2005. *Changes of the abiotic conditions in the lakes of north-east Poland*. UMK, Toruń.

Napiórkowska-Krzebietke A., Stawecki K., Pyka J. P., Zdanowski B., Zębek E. 2016. *Phytoplankton and the physicochemical background in an assessment of the ecological and trophic conditions in vendace-type lakes*. J. Elem., 21(1): 159-172. DOI: 10.5601/jelem.2015.20.2.891

Naselli-Flores L., Barone R., Chorus I., Kyrmayer R. 2007. *Toxic cyanobacterial blooms in reservoirs under semiarid Mediterranean climate: the magnification of a problem*. Environ. Toxicol., 22: 399-4104.

Nawrocka L., Kobos J. 2011. *The trophic state of the Vistula Lagoon: an assessment based on selected biotic and abiotic parameters according to the Water Framework Directive*. Oceanologia, 53(3): 881-894.

Nöges T, Laugaste R., Nöges P., Tönno I. 2008. *Critical N:P ratio for cyanobacteria and N2-fixing species in the large shallow temperate lakes Peipsi and Vortsjarv, North-East Europe*. Hydrobiologia, 599: 77-86. DOI: 10.1007/s10750-007-9195-x

Oberholster J.P., Botha A.M., Cloete T.E. 2006. *Toxic cyanobacterial blooms in a shallow, artificially mixed urban lake in Colorado, USA*. Lakes & Reservoirs: Res. Manage., 11: 111-123.

Saghi H., Karimi L., Javid A.H. 2014. *Investigation on trophic state index by artificial neural networks (a case study: Dez Dam of Iran)*. Appl. Water Sci., 5(2): 127-136.

Schueler T., Simpson J. 2001. *Why urban lakes are different?* Water Protect. Techniq., 3(4): 747-750.

Tátrai I., Boros G., György Á.I., Mátyás K., Korponai J., Pomogyi P., Kucserka T. 2009. *Abrupt shift from clear to turbid state in a shallow eutrophic, biomanipulated lake*. Hydrobiology, 620(1): 149-161. DOI: 10.1007/s10750-008-9625-4

Vollenweider R.A., 1976. *Advances in defining critical loading level for phosphorus in lake eutrophication*. Mem. Inst. Ital. Hydrobiol., 33: 53-83.

Xie L., Xie P., Li S., Tang H., Liu H. 2003. *The low TN:TP ratio, a cause or a result of Microcystis blooms?* Water Res., 37(9): 2073-2080.