VILNIUS TECH
Vilnius Gediminas Technical University

12th International Conference
ENVIRONMENTAL ENGINEERING
April 27–28, 2023, Vilnius, LITHUANIA

eISSN 2029-7092
eISBN 978-609-476-342-7
Article ID: enviro.2023.854
https://doi.org/10.3846/enviro.2023.854

STUDY ON THE INFLOW OF BIOGENIC SUBSTANCES INTO LAKES

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Received 16 January 2023; accepted 20 February 2023

Abstract. Changes in the ecosystems of lakes and their shores caused by anthropogenic impact have a huge influence on the quality of the landscape. The article analyzes the inflow of biogenic substances into lakes Lūkstas and Paršežeris. The spread of Quaternary sediments of lake basins, land use distribution, ongoing economic activities, activity planning and the effectiveness of water conservation measures in the dry year of 2020 was analyzed to study in detail. The planned and actual amounts of biogenic substances entering the lakes through seven surface water tributaries were evaluated. It has been established that the environmental protection measures implemented in the Lūkstas and Paršežeris lakes basins over the last decade are effective. Calculations and analysis of the loads of biogenic materials in the investigated lake tributary basins based on the results of natural studies showed that the values of biogenic material loads do not exceed the values modeled in the modeling done in the work and in the river basin management plans.

Keywords: biogens, lake pollution, anthropogenic activity, diffuse pollution, ecological condition.

Introduction

Lakes are one of the most important elements of the landscape, shaping its aesthetic, recreational, cultural, economic, nature conservation and commercial value. However, anthropogenic eutrophication, which is caused by intensive anthropogenic activities in the lake basin, causes lakes to lose their ecosystem functions, which is a major ecological problem (Kronvang et al., 2008). Anthropogenic pollution sources are divided into two main groups according to their mode of action: concentrated and diffuse pollution sources. Sources of diffuse pollution can include pollution from agricultural activities, such as manure and mineral fertilizer loads, and pollution from residents whose households are not connected to wastewater collection networks (Brack et al., 2007). Diffuse pollution is much more difficult to assess and control than concentrated pollution, because specific sources of pollution and the extent of pollution are not known. Changes in lakes and their coastal ecosystems caused by anthropogenic impact have a huge influence on the quality of the landscape. The most noticeable changes occurred in small and shallow lakes. In most of them, coastal swamping is visible, the part of the basin of the water body or even the entire area of the lake is continuously overgrown with macrophytes rooted in the bottom. Planktonic microalgae cause "water blooms" that reduce the recreational value of the lake during the summer. Disruption of the hydrochemical cycles and gas exchange regime is a direct factor in the lack of oxygen in the lake, which causes fish to suffocate in winter (Balevičius et al., 2009; Savadova-Ratkus et al., 2022). Considering how water bodies are affected by anthropogenic pollution, it is necessary to carry out detailed studies of lake water and apply optimal measures to achieve a good condition of water bodies at risk. The purpose of the study is to investigate the water quality of the tributaries of Lake Paršežeris and Lake Lūkstas, taking into account diffuse and concentrated pollution, and to analyze trends in the concentration of biogenic substances and to propose measures to reduce pollution of water bodies.

Materials and methods

The analysis of indicators of elements of physico-chemical quality (dissolved oxygen, biochemical oxygen consumption for 7 days, ammonium, nitrates and nitrites and total nitrogen, levels of phosphates and total phosphorus) of the water was carried out, from seven streams, canals, or drainage ditches flowing into Paršežeris and Lūkstas lakes (Figure 1). Researches were conducted 7 times a year of 2020 (March, April, May, September, October, November, December).

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Figure 1. Basins of lakes Paršežeris, Lūkstas and analyzed tributaries

Inflows of biogenic substances into water bodies are caused by precipitation, land use and the sediment structure of the basin (Litvinaitis, 2013). Databases of meteorological, hydrological parameters and land use of the studied river basins were created for the complex analysis of the lakes and studied tributaries. Aerial photos, lithological, geomorphological, land use, hydrographic maps and digital databases were used for their compilation. The change of the water balance, the migration of the considered biogenic substances in the tributary basins of the considered lakes, and the dependences of the change were determined by statistical methods and by applying mathematical modeling. According to the composition of the basin's sediments, three classes of sediments are distinguished when evaluating the filtration coefficients: sand, loam-sand (hereinafter – loam), clay. Filtration coefficients of basic mineral deposits are applied to peat (Litvinaitis, 2013). Given the fact that the studied basins are relatively small, the basins are not divided into parts (segments), divided into tributary sections. ArcGis software was used for detailed analysis of sediment and land use distribution in the watershed. Perpendicular to the river axis, 0–50 m, 50–200 m, 200–500 m, 500–800 m, 800–1100 m and >1100 m wide estuarine sections were distinguished, in which the distribution of sediments and land uses was assessed as a percentage of the area of the estuary section. Determining the amount of water in a river basin entering rivers through subsurface runoff requires an assessment of several environmental components (precipitation, evaporation, runoff, surface decomposition, sediments, and land use structure). Empirical formulas describing the quantitative values of the mentioned components were used for such assessment. Part of the precipitation filters into sediments and enters the river bed through underground runoff. The water balance equation was used to define this process

$$R = \sum_{i=1}^{f} \left[\left(K_f - E_f \right) \cdot A_f \cdot \left(\frac{1}{2} \cdot \frac{L_f}{v_f} + \sum_{i=1}^{f+1} \frac{L_{f+1}}{v_{f+1}} \right) \right],$$

where: R is the height of the leak (mm); f – tributary section, counting from the furthest >1100 m section to the river; K_f – amount of precipitation per tributary section (mm/d); E_f – total evaporation in the tributary section (mm/d); A_f – area of the inlet section (km^2); L_f – section width (m); L_{f+1} – width of the estuary section closer to the river (m); v_f – water filtration rate in the tributary section (m/d); v_{f+1} – water filtration rate in the tributary section closer to the river (m/d) (Litvinaitis, 2013; Litvinaitis et al., 2015).

The anthropogenic loads of the fields are mainly determined by the fertilizing of agricultural plants with mineral and organic fertilizers. Where there is no centralized sewage network, human waste is also spread in the fields and gardens. The quantities of mineral fertilizers used are most accurately determined by accounting journals kept by farmers, but currently there are few such farmers. Therefore, where there is no accounting of fertilizers, the anthropogenic loads of the fields are determined according to the amounts of fertilizers used in the administrative districts and presented in the statistical yearbooks. Similarly, the anthropogenic load of fields with animal manure is calculated, but here the concept of the so-called "conditional animal" is used as a benchmark (Prišaitė et al., 2021).

In order to determine the amount of biogenic substances entering the lakes, water measuring stations are installed at the water quality research sites to measure the flow rate.

Specific measures to improve the ecological condition of lakes are selected individually for each water body, depending on the identified problem (Aplinkos apsaugos agentūra, 2020).

Results and discussion

The Venta River Basin Districts (RBD) management plan was evaluated, in which it was predicted that concentrated pollution loads will decrease slightly in the near future, as a relatively high level of wastewater treatment has already been achieved. Compared to 2012 concentrated pollution data with the 2008–2009 data used for planning, a rather significant reduction of pollution loads can be seen in the Venta RBD. While total effluent increased by 10%, total nitrogen loads decreased by 14% and total phosphorus by 54%, but BOD7 pollutant loads increased by as much as 40%. The agricultural pollution load consists of the amount of nitrogen and phosphorus compounds entering the soil with animal manure and mineral fertilizers (Aplinkos apsaugos agentūra, 2017).

The calculations performed (Aplinkos apsaugos agentūra, 2017) shows that the reduction of diffuse agricultural pollution in the Ventos RBD is necessary in an area of 1800 km^2. In order for agricultural pollution to no longer have a significant impact on the state of water bodies, leaching of nitrate nitrogen should be reduced by an average of 1.4 kg/ha. A similar pollution reduction goal – a reduction of nitrate nitrogen leaching by 1.2 kg/ha – was set in the first UBR management plan.

Lakes Paršežeris and Lūkstas fall into the basins of water bodies that are significantly affected by widespread agricultural pollution (Aplinkos apsaugos agentūra, 2017).

Analysis of Quaternary sediments was carried out. 15% of the basin of Lake Lūkstas (basin area 79.9 km^2) is covered by water bodies, most of them – lakes Lūkstas and Paršežeris. Loam and sand deposits cover 33% and 20%, respectively, and there are clay (3%) inclusions (Figure 2).

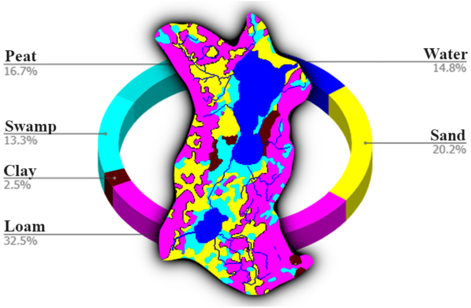

Figure 2. Spread of Quaternary sediments in the basin

Swamps cover 13%, peat bogs 17% of the area of the basin, concentrated on the shores of lakes. Forests and other natural areas cover 29% of the basin area, deciduous forests dominate (19%). The remaining 57% of the basin is an agricultural area, dominated by complex agricultural areas (29%), pastures (16%) and cultivated land (11%) (Figure 3).

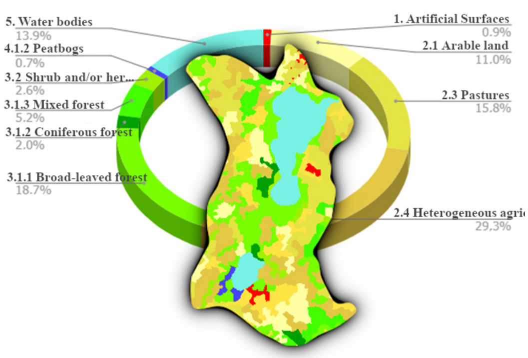

Figure 3. Spread of land use in the basin

The basin of Lake Paršežeris was evaluated separately, as well as the basins of all analyzed intakes: the distribution of sediments and land use was analyzed.

Hydrological drought was fixed in summer 2020 (Lietuvos hidrometeorologijos tarnyba, 2020). Higher than normal precipitation in winter and early spring (long-term average 1.2-2.4LA) was replaced by a dry end of spring and early summer (0.3-0.6LA) and a dry summer (0.3-1.1LA), characterized by heavy rainfall.

49 water quality tests were carried out at 7 research sites during the research period, the months of March-December (Table 1).

During the study period, the total nitrogen concentration for the most part showed very good and good condition of the studied water bodies. Concentrations indicating poor status were found in a small basin of up to 3 km^2 in December. Average – December and March. The poorer condition was due to nitrate concentrations. Total phosphorus samples in very poor and poor condition were determined in May and October, possibly due to wastewater from residential areas.

The BOD7 parameter values of water bodies can be affected by anthropogenic pollution: concentrated and diffuse pollution sources. The main sources of concentrated pollution that determine the BOD value are urban and rural sewage treatment plants, paper, food and meat processing plants' wastewater discharges (Merrington et al., 2002), which are not so abundant in the analyzed areas. Diffuse pollution is more likely to be runoff from agricultural areas, cities and animal husbandry complexes. The BOD parameter indirectly shows the amount of biologically available organic substances in water. Organic materials are also transported to rivers and lakes from swamps, where there is usually a lot of organic matter (Aplinkos apsaugos agentūra, 2010), which is very likely, especially since the concentrations of ammonium nitrogen (47 cases out of 49) met the criteria of very good condition, which indicates the natural origin of BOD7 concentrations.

After modeling the anthropogenic loads of fields used for agricultural purposes, it was determined that the highest expected anthropogenic loads are from livestock. By modeling, it was quantified how many biogenic substances can enter the studied lakes (Table 2).

Table 1. Water research results

Substance	Conc. Min, mg/l	Conc. Max, mg/l	Recurrence / Condition of water bodie				
			v. good	good	average	bad	v.bad
NO_3-N	0.225	4.157	38	6	5	0	0
NH_4-N	0.015	0.405	47	1	1	0	0
BDS_7	6.4	25	0	0	0	2	47
N_t	0.149	6.2	34	8	6	1	0
P_t	0.031	0.327	45	2	1	1	0
PO_4-P	0.021	0.304	39	7	1	2	0
O_2	0.99	14.43	11	5	15	8	10

Table 2. Inflow of biogenic substances (t/m) to the studied lakes, modeling results

Basin	From all basins				From cultivated fields			
	N_t	N_t*	P_t	P_t*	N_t	N_t*	P_t	P_t*
Lūkstas	92.47	81.71	7.57	6.92	71.75	65.88	7.47	6.85
Paršežeris	29.47	17.17	2.51	1.42	23.25	13.18	2.48	1.05

Note: N_t, P_t – inflow from lake basin; N_t*, P_t* – inflow from.

The loads with biogenic substances do not exceed the minimum values of the loads given in the management plans of the Ventos RBD (Aplinkos apsaugos agentūra, 2017).

After analyzing the flows transported by the tributaries of Lakes Lūkstas, it was determined that 21.7 tons of total nitrogen entered the lake during the study period from all studied tributaries of Lake Lūkstas. The inflow in different months varied from 0.093 to 2.98 t per month, and the average inflow per tributary was 0.76 t Nt per month (Table 3).

Evaluating the input of total nitrogen in kilograms per unit of area per month (kg/ha/month), material loads are obtained from 0.06 to 2.3 kg/ha/month, on average 0.78 kg/ha/month.

During the research period, 4.5 tons of total nitrogen, as much as 60 percent, were brought into Lake Paršežeris through the analyzed tributaries, entered in March and December (Table 4). The average tributary through all investigated tributaries is 318 kg/month. Evaluating the total nitrogen inflow of all tributaries in kilograms per unit of basin area (ha) monthly loads from 0.03 to 2.2 kg/ha/month, on average 0.57 kg/ha/month.

After analyzing the significant sources of concentrated pollution of all lakes, it was found that no wastewater is discharged into Lakes Lūksta and Paršežeri, although the risk due to wastewater is possible, but it has not been identified. After evaluating the results of diffuse pollution studies, it can be stated that diffuse pollution becomes evident in small basins of water bodies and in the presence of loam and clay sediments. When evaluating individual basins of tributaries to the lake, it is important to take into account the number of agricultural entities, not only the areas of cultivated land. The research established that the method of farming, applied environmental protection measures (coastal protection strips), marshy areas in the basins create conditions for the studied tributaries of the lakes in good and good condition during dry and moderately dry periods. It is likely that during periods of moderate and higher water content, the intensity of leaching from agricultural areas and the water quality of streams will decrease.

Well-known engineering and technical measures are proposed, such as artificial wetlands, sedimentation ponds, coastal protection strips/zones of water bodies, drainage runoff management systems, denitrifying bioreactors in drainage systems, etc (Punys et al., 2019; Aplinkos apsaugos agentūra, 2016; Povilaitis, 2015). However, it should be noted that some of the measures related to the installation of wetlands are not recommended (Povilaitis et al., 2011; Stachowicz et al., 2022), because wetlands cover 7–22% of the basin area of the analyzed tributaries. Results of nitrogen retention in riparian buffers vary widely in the literature, but collectively, up to 74.2±4.0% of nitrogen can be retained in water flowing through a riparian ecosystem (Hickey &

Table 3. Inflow of biogenic materials through tributaries to Lake Lūkstas, kg

Subst./ month	3	4	5	9	10	11	12	Total
N_t	5750	2097	2754	1727	2100	2960	4333	21 721
NO_3-N	3375	526–718	68–469	39–269	102–410	1237	2510	7857–8988
NH_4-N	0–25	0–30	0–28	71–81	0–24	0–27	0–25	71–240
P_t	103	163	124	43	66	228	125	852
PO_4-P	91	93	96	35	56	209	109	689

Table 4. Inflow of biogenic materials through tributaries to Lake Paršežeris, kg

Subst./ month	3	4	5	9	10	11	12	Total
N_t	1669	184	518	51	525	457	1053	4457
NO_3-N	983	26–50	0–89	0–10	0–89	177	390	1576–1788
NH_4-N	0–8	0–2	0–6	4–5	0–6	0–4	0–8	4–39
P_t	20	6	20	1	16	14	62	139
PO_4-P	17	3	16	1	11	13	56	117

Doran, 2004). Comparing the results of research conducted by various authors, a statistically significant dependence was found between the width of the coastal protective strips and the efficiency of nitrogen removal. 50%, 75%, and 90% nitrogen removal efficiency is obtained when the width of coastal protection strips is 3, 28, and 112 m, respectively (Mayer et al., 2006, 2007; Pacioglu et al., 2022; Liu et al., 2017). During the distribution of coastal protection strips, the areas of the fields around the river and the ditch inevitably decrease. The preliminary cost of installing a protective strip is 303.5–1007 Eur/ha, the cost effectiveness is 6.10–58.8 Eur/kg N and 5.03–261.4 Eur/kg P per year (Bastienė & Kirstukas, 2010) shows the clear benefits of distributing safety strips.

Conclusions

After analyzing the change in the water quality of Lake Lūkstas during 2013–2019. period, it was found that the concentrations of total nitrogen corresponded to a good ecological class and the water quality remains stable. The change trends in the concentration of total phosphorus are increasing even up to 30%, although they reach a good ecological class, while considering the change in BOD7 concentrations, a decreasing trend of about 20% is observed, up to a good ecological class.

The concentration of total nitrogen in Lake Paršežeris decreases by up to 20% during the considered period and corresponds to a good ecological condition. The amount of total phosphorus in the lake water increases by about 10%, but still corresponds to a good ecological class. BOD7 concentrations remain constant and correspond to a good ecological status class. The environmental protection measures implemented in the basins of lakes Lūkstas and Paršežeris are effective.

According to the concentrations of total nitrogen, the water bodies corresponded to very good and good condition, with the exception of the small, up to 3 km^2 nameless tributary of Lūksta, classified as average. In terms of total phosphorus, all water bodies corresponded to very good status.

Calculations and analysis of the loads of biogenic materials in the investigated lake tributary basins based on the results of natural studies showed that the values of biogenic material loads do not exceed the values modeled in the modeling done in the work and in the river basin management plans. It was established that the load with biogenic substances during the research period changed regularly in relation to the time of year and the intensity of land use.

It was established that the method of farming, applied environmental protection measures (protection zones), marshy areas in the basins and the existing ones create conditions for the studied tributaries of the lakes in good and good condition during dry and moderately dry periods.

Acknowledgements

Sincerely acknowledgements for Justas Samosionokas (Ecojuris, MB) for research management and organization activities.

Funding

Results of the research were obtained during the implementation of the project "Research of water bodies, identification of pollution sources and preparation of measures to improve the condition of water bodies", (executor Ephitas, VšĮ, customer Environmental Protection Agency, EU SF project 05.3.1-APVA-V-011-01-0008, "Investigations and evaluations of the environmental status of inland waters").

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