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The ecological condition of the Lasvinsky lakes, Perm, Russia

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Abstract

The total area of the water surfaces in the Perm is 60.4 km^2. Among the surface water resources, lakes and swamps play an important role. They are reservoirs of available water that form the ecological state of the territory. The Lasvinsky lakes (that have a total area of around 1247 hectares) are wetlands that can be classified as specially protected areas, which are of particular importance for the conservation, restoration and maintenance of wetland communities, waterfowl resources and their habitats. These water bodies are located in Perm. This million city with a developed engineering infrastructure and powerful industrial enterprises inevitably has a negative impact on the environment, including the water bodies. The Lasvinsky lakes experience significant anthropogenic impact, which affects the current ecological situation. It has been established that the Lasvinsky lakes are of natural origin, their main source is groundwater, the level of which is determined by the regulation of the Votkinsk reservoir. The lakes have different self-cleaning abilities and different conditions for the hydro-chemical regime formation and it helps water productivity.

Keywords: Bottom Sediments; Hydro-Biological Indicators; Hydrochemistry; Pollution; Water Productivity; Wetland Complex

INTRODUCTION

The main waterway of Perm is the Kama river, which has historically become the city-forming axis of Perm. More than 300 small rivers and streamflow into the Kama and form an intercity river network. It includes lakes, ponds and swamps. The total area of the water surfaces in the city is 60.4 km^2 (Dvinskikh *et al*., 2017). Among the surface water resources, lakes and swamps play an important role. They are reservoirs of available water that form the ecological state of the territory. However, insufficient knowledge of the quantitative and qualitative indicators of their waters does not contribute to their rational use (Zaky *et al*., 2011). At the same time, these water bodies are used for various economic purposes, which gradually leads to changes in their ecological state: their hydrobiological and hydrochemical indicators. The purpose of these studies is to explore the ecological state of the Lasvinsky lakes, Perm State, Russia.

MATERIALS AND METHODS

The research was done with use of the fieldwork data from summer 2017 by the authors, according to the standard methods.

The geomorphological and hydrographic surveys of lakes and adjacent territories. Several morphometry characteristics of studied lakes have been determined: surface area, length, maximum and average width, coastline length.

The bathymetric survey was done with use of the SonarTRX equipment during navigation time. The digital maps of the lakes bottom were received.

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Some physical characteristics including water transparency according to the Secchi disk, water turbidity, vertical variation of water temperature were observed.

Water and bottom sediments were sampled to determine the content of the following substances and indicators: HCO^{3-}, Cl^{-}, $SO4^{2-}$, NH^{4+}, NO^{3-}, NO^{2-}, PO_4^{3-}, Fe, Cu, Zn, Mn, oil products, dissolved oxygen, COD, BOD_5. Chemical-analytical studies were performed in a certified laboratory.

The hydrobiological studies included determination of biomass abundance, species composition of zoobenthos and macrophytes, overgrown areas of lakes. To assess the ecological state of the lakes were selected Oligochaete index, Goodnight-Whitley Index, King-Ball Index.

The Lasvinsky lakes are located in the right-bank floodplain of the Kama. They are of riverine origin associated with the erosion and accumulative activity of the river. The largest lake is Bolshoye Lasvinskoye, followed by Dikoe, Lobkhanskoye and Maloye Lasvinskoye (Fig. 1).

Bolshoye Lasvinskoye lake has an irregular shape, elongated from northwest to southeast. The lake area is 0.36 km^2, the length is 2 km, and the average width is 0.2 km. The lake is surrounded by a coniferous forest, along the perimeter there are lowland swamps (Fig. 2). They are formed by the spring and summer floods in the conditions of a ground-type water supply. The latter is associated with a significant increase in the level of groundwater as a result of the creation of the Kamskaya Hydroelectric Power Plant dam. Groundwaters, in our opinion, are the main resource of the Lasvinsky lakes. The greatest depths reach 6.0 m in the central part; in bays, they range from 0.5 to 2.0 m. The growth occurs most intensively in the coastal parts, the deep-water part of the lake is clear. The transparency of the water is 80-85 cm throughout the entire water area. Through the water area of the lake, wastewater from an industrial enterprise is discharged into the Votkinsk reservoir (Lepikhin and Perepelitsa, 2011).

A unique situation has developed on this lake: on the one hand, it is a receiver of wastewater from a large enterprise, and on the other, it is experiencing a weak anthropogenic impact associated with recreation and fishing (Dvinskikh *et al*., 2017; Lepikhin and Perepelitsa, 2011; Vlasova, 1974).

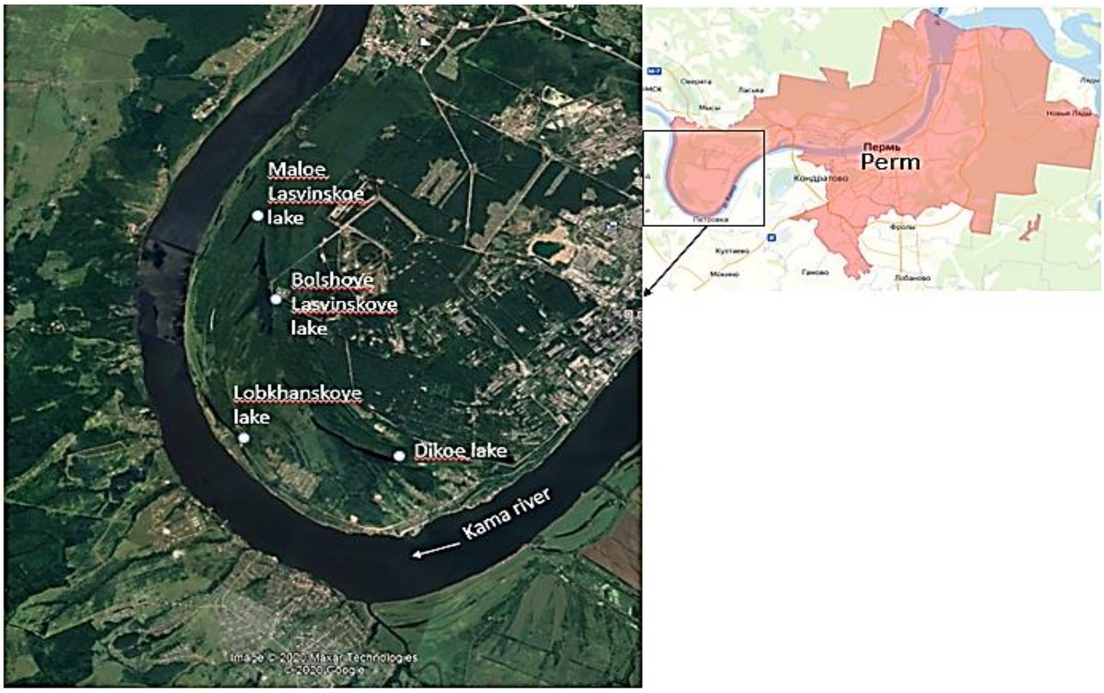


Fig. 1. The location of the study area

Maloe Lasvinskoe lake is located to the west of Bolshoye Lasvinskoe lake. The area of the lake is 0.04 km^2, its length is 0.7 km, and the average width is 0.06 km. Maloye and Bolshoye Lasvinskoye lakes and Votkinsk reservoirs are interconnected by artificial canals, through which the water flows from Bolshoye Lasvinskoye lake into the reservoir.

Dikoe lake is surrounded by a coniferous forest and is the most accessible for recreation (Fig. 3). The lake area is 0.12 km^2, the length is 1.57 km, and the average width is 0.07 km. It is characterized by the overgrowth of the coastal parts with higher aquatic vegetation, the transparency of the water is 120 cm.

Lobkhanskoye lake is small in size, warms up well in the summer months and is actively overgrown. The area of the lake is 0.07 km^2, its length is 1.52 km, and the average width is 0.04 km. For reasons unknown to us, the lake was divided into three parts. As a result, the central part, which is small in size and well warmed up in the summer months, is currently overgrown. Its overgrown area is more than 90%. The edge parts of the lake are quite clear (Fig. 4 *a* and *b*).

The ecological situation of the Lasvinsky lakes is a result of external (associated with point and diffuse sources of pollution) and internal factors.

Fig. 2. Bolshoye Lasvinskoe Lake in summer 2017

Fig. 3. Dikoe Lake in summer 2017

Fig. 4. Lobkhanskoye lake: a) its marginal part, b) its central part

RESULTS AND DISCUSSION

The external and internal factors and also hydro-biological indicators are described and discussed here.

The external factors are natural and technogenic

The natural factors include the lithology of the rocks that make up the catchment area and the composition of groundwater drained by the valleys. The technogenic factors are the industrial wastewater discharges. A smaller contribution is made by storm and melt water flowing down from the surface of the catchment area (Dvinskikh *et al*., 2014).

The chemical composition analysis shows that the waters of the studied lakes are fresh and belong to the hydrocarbonate-sulphate-calcium facies. They have an average hardness and are slightly alkaline. The waters of the lakes comply with sanitary standards according to the value of mineralization, the content of the main ions, as well as by the concentration of nitrates and nitrites. An exception is the excess in copper, zinc, manganese, and total iron, which is typical for the whole system of the studied lakes. The high amount of iron can be easily seen: the color of the water changes from light yellow to brown.

The strongest technogenic impact within the urbanized territory affects not only the waters, but also the bottom sediments covering the channel. The specificity of transport and accumulation of industrial pollution in the aquatic environment and in bottom sediments is fundamentally different. In this regard, the environmental analysis of these areas is made according to various indicators. Unfortunately, no common criteria for determining the quality of bottom sediments have been developed. Therefore, various standards for soil are used to assess their quality (Rumyantsev and Drabkova, 2015; Shitikov *et al*., 2003). The pollution of bottom sediments of the Lasvinsky lakes was determined by the presence and content of heavy metals, because they are subject to accumulation and are slightly involved in movement. The analysis of the chemical composition of the bottom sediments insignificantly exceeded the copper and zinc TLV (threshold limit value). The content of lead, iron and petroleum products does not exceed the TLV.

The internal factors include hydrological and oxygen conditions

The hydrological regime determines the mechanical processes of purification (dilution), while the oxygen regime determines the processes of destruction.

The hydrological regime of the Dikoe and Lobkhanskoe lakes is typical for reservoirs with slow water exchange. It is characterized by insignificant flow rates and weak convection; it does not play a significant role in the self-purification of the reservoir. During the period of high water content and wastewater discharge, the lakes become flowing. This affects the processes of self-purification and the formation of biological productivity of aquatic ecosystems.

The oxygen regime is also one of the most important factors determining the intensity of self-purification processes and the formation of biological productivity of aquatic ecosystems. The oxygen deficiency resulting from a decrease in the intensity of atmospheric and photosynthetic aeration, with a simultaneous increase in its consumption for biological and chemical oxidation of organic matter, has a negative impact on the functioning of the main links of the ecosystem and water quality.

The content of the dissolved oxygen varies from 2.16 mg/l in Lobkhanskoye lake (oxygen deficiency) to 5.58 - in Bolshoye Lasvinskoye lake (sufficient oxygen saturation of the waters). In the Bolshoye and Maloye Lasvinsky lakes, the self-cleaning ability is higher due to the peculiarities of the hydrological regime (the rate and water exchange are much higher than in the other two).

The group of processes that reduce the oxygen content in water includes the reactions of its consumption to the oxidation of organic substances, i.e. in a reservoir a lower oxygen content may be associated with high concentrations of polluting organic substances coming from the catchment area, as well as with the content of a large amount of biogenic and humic substances. Their quantity can be judged by the values of BOD (biochemical oxygen demand) and COD (chemical oxygen demand).

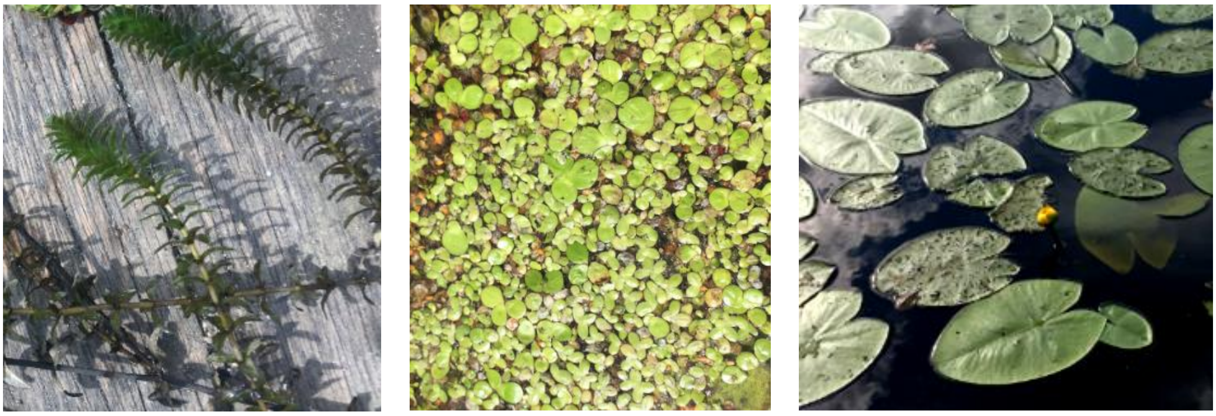
COD determines the costs associated with the chemical reactions of elements and compounds in the composition of water, while the BOD value determines the oxygen consumption required for the oxidation of simple organic compounds due to the action of aerobic bacteria. The higher these indicators are (oxygen consumption, oxygen absorption), the more intense the water pollution is; the more intense the pollution is, the more oxygen will be required for its elimination.

The BOD values$_5$ at the surface in the middle of summer vary from 3.9 mg O_2/l (Lobkhanskoye lake) to 4.3 (Bolshoye Lasvinskoye lake). This indicates different classes of pollution. The waters of Lobkhanskoye lake are polluted, and the waters of the Dikoe, Maloe Lasvinskoe, Bolshoye Lasvinskoe lakes are dirty. In terms of COD (varied from 48 mgO_2/l in Bolshoye Lasvinskoye lake to 67 mgO_2/l in Dikoe lake), the waters of the lakes can be classified as very dirty.

Hydrobiological indicators

Water bodies are the habitat of coastal aquatic vegetation. The life of many aquatic invertebrates, insects, fish, birds, mammals is associated with the thickets of macrophytes (Bakanina *et al*., 2001; Barieva, 2003; Baturina *et al*., 2012). The species diversity of animals, bacteria and fungi in macrophyte thickets is much higher than in the open parts of the water bodies; there’s an abundance of biomass of benthic, planktonic and periphytonic organisms. The aquatic vegetation has a great influence on the hydrochemical regime of water bodies; it regulates the concentration of oxygen and carbon dioxide in the water, influences the mineral composition of waters, acidity, etc. In the growing zone of submerged plants, physicochemical processes are more dynamic than in the open areas. This is facilitated not only by the plants themselves, but also by their fouling (periphyton), bacteria, planktonic and bottom organisms. The coastal aquatic plants play a great role in the purification of water bodies from organic and mineral pollutants. In the destruction of pollutants, an important role is played not only by the plants themselves, but also by microorganisms (bacteria, algae, fungi) that live on their surface. After dying off, the coastal aquatic vegetation becomes food for benthic organisms. Still, the excessive development of coastal aquatic vegetation leads to overgrowth of the reservoir and its degradation.

There have been seven taxa identified in the higher aquatic vegetation of the Lasvinsky lakes. In the coastal zone there are lots of *Carexs pp.* sedges, *Alisma plantago-aquatica* Plantain ditches, as well as the common arrowhead *Sagittaria sagittifolia* that are often found (Fig. 5). The marsh cinquefoil *Comarum palustre* is found rarely. The coastal zone is followed by a belt of submerged vegetation and vegetation with floating leaves, among which *Elodea canadensis* predominates. *Lemna minor* is abundant on the water surface. Lush development of common arrowhead, plantain daisy and *Elodea canadensis* indicates the presence of organic pollution. It is worth noting the presence of the yellow capsule *Nuphar lutea (L.)* on the surface along the shores of the Bolshoye Lasvinskoye and Dikoe lakes. It grows in lakes, ponds, oxbows, slow-flowing rivers; it blooms in the second half of June and July. This species is predominantly oligo- and beta-mesosaprobic, but lives in a wide range of saprobic conditions and can withstand moderate organic pollution.



Elodea Canadensis *Lemna minor* *Nuphar lutea (L.)*

Fig. 5. Examples of higher aquatic vegetation of the Lasvinsky lakes

Bottom animals and their communities are a good indicator of ongoing changes in the natural environment (Bayanov, 2002; Vislyanskaya, 1999; Vlasova, 1974). Since the life cycle of most representatives of the bottom fauna is several months, and sometimes years, their communities accumulate changes in the conditions of existence over sufficiently long periods. Therefore, during the biological analysis of waters, it is important to take into account the state of the bottom communities. Unfortunately, the ecosystems of water bodies located in Perm are still poorly studied or not studied at all. This also applies to the Lasvinsky lakes.

The lake zoobenthos contains six taxa. Gastropoda is represented by three species. Among the bivalve mollusks (Bivalvia: Unionidae), the toothless Anodontacygnea was found. The larvae of bell mosquitoes (Chironomidae) and small-bristle worms (Oligochaeta: Tubificidae) each have one species. The material analysis made it possible to establish that a qualitatively depleted zoobenthocenosis was formed in the profundal of the lakes, in which the gastropods *Bithynia tentaculata* dominate. The biomass of the benthic fauna is 1.8-26.85 g/m^2 with a number of 0.2-0.9 thousand ind./m^2 (Table 1). It is noteworthy that the basis of the bottom fauna is made up of gastropods, ecologically associated with higher aquatic vegetation. This applies to the typical phytophils – *Lymnae astagnalis* and *Lymnae aampla* pond snails. The benthic forms are represented only by chironomid larvae and tubuleworms, the biomass of which is in the range of 0.6-0.8 g/m^2.

Among the six invertebrate species found in the zoobenthos of the Lasvinsky Lakes,

Table 1. Taxonomic composition, abundance (ind/m_2, above the line) and biomass (mg/m^2, below the line) of the lakes' zoobenthos

Taxon	Zoobenthocenosis			
	Bolshoye Lasvinskoye lake	**Dikoe lake**	**Maloye Lasvinskoye lake**	**Lobkhanskoye lake**
Oligochaeta: Tubificidae				
Limnodrilus hoffmeisteri	200/1500	100/800		100/1000
Diptera: Chironomidae				
Polypedilum nubeculosum	100/600	100/800	100/700	100/800
Mollusca: Gastropoda				
Lymnae astagnalis	100/6550	-	100/4500	-
Lymnaea ampla	100/4000	-	100/3000	-
Bithynia tentaculata	400/14200	100/3200	200/7500	
Total:	**900/26850**	**300/4800**	**500/15700**	**200/1800**

only three can be classified as forage species. These are the small-bristled worms Limnodrilushoffmeisteri, larvae of the bell mosquitoes Polypedilumnubeculosum, and the gastropods Bithyniatentaculata. Pond snails and toothless animals, due to their large size in the definitive state, are not consumed by the representatives of the local ichthyofauna.

The biomass of food organisms in the Lasvinsky lakes is in the range 4.8-16.3 g/m^2. The approximate production of zoobenthos in the range of 14.4-48.9 g/m^2 can provide the potential fish productivity of the water area within 37-127 kg/ha.

The ichthyofauna of the Lasvinsky lakes includes eight species, among which the representatives of the cyprinid family Cyprinidae (six species) prevail. Along with them, the representatives of the families of pike Esocidae and perch families Percidae were noted. All these fish are quite common in Perm Krai.

The analysis of the literature has shown that to date, various methods have been developed for assessing water quality by the composition of benthic animals (Barieva, 2003). The Kolkwitz-Marson system of indicator organisms in Zelenka and Morvan, Pantley and Buk modifications has gained particular popularity in European countries. However, in the conditions of Russia, proved by the studies by Finogenova and Alimov (1976), this method for assessing the pollution of a reservoir is inapplicable in many cases. One of the main reasons for this is the difference in the fauna of Central European water bodies. Also, in order to assess the water quality of pond-lake systems, the proposed methods have to be modified taking into account the habitat conditions of aquatic organisms.

It has long been noted that some groups of aquatic insect larvae, as a rule, are found in clean waters, while oligochaetes, on the contrary, not only tolerate pollution well, but also create a large population, mainly tubificids.

To assess the ecological state of the lakes, the following parameters were selected (Table 2) (Aquatic, 1989; Dauvalter, 1998):

1. Oligochaete index. The degree of pollution is determined by the absolute number of oligochaetes in benthic communities (N_o). At N_0 = 100-1000 ind./m^2 means low pollution; N_0 = 1000-5000 specimens/m^2 means average pollution; $N_0 \geq$ 5000 ind./m^2 means heavy pollution.

2. Goodnight-Whitley Index. When assessing the degree of pollution, the ratio of the number of oligochaetes to the total number of animals of benthos (No / Nb) is taken into account. If this indicator is less than 60%, the condition of the reservoir is good; 60-80% - doubtful condition; more than 80% - poor condition.
3. King-Ball Index. The index takes into account the ratio of insect biomass to oligochaete biomass. When contaminated, the index is zero or less than one: 0.1-0.4 means dirty, 0.4-0.9 means heavily contaminated. In all cases, the number and biomass of animals is calculated per 1 m^2.

The complex of biological indicators (Table 2) characterizes the studied lakes as relatively clean.

CONCLUSION

Lasvinsky lakes are of natural origin, their main source is groundwater, the level of which is determined by the regulation of the Votkinsk reservoir. They have different self-cleaning abilities, different conditions for the formation of a hydrochemical regime. On the Bolshoye and Maloye Lasvinsky lakes, the self-cleaning ability is higher, due to the peculiarities of the hydrological regime (the rate and water exchange are much higher than in the other two).

According to the BOD, the waters of Lobkhanskoye lake are classified as polluted, and the waters of the Dikoe, Maloye Lasvinskoe, and Bolshoye Lasvinskoe lakes are dirty. In terms of COD, the lake waters can be classified as very dirty. The COD values up to tens of mg / l indicate a high content of organic substances (both of natural and technogenic origin) and are caused by their active washout from the catchment surface. No developmental defects or a depressed state are observed in plants. The zoobenthos of the lakes is characterized by a low taxonomic diversity, a simplified structure and rather high indicators of abundance and biomass. An assessment of the ecological state of the Lasvinsky lakes according to biological indicators showed that the state of the lakes is satisfactory, the quality of the water is relatively clean.

According to the resolution No. 782 of Perm administration dated October 28, 2014 - "The approval of a comprehensive development plan for the system of specially protected natural areas of local importance in Perm" - the territory of the Lasvinsky lakes (that has a total area of around 1247 hectares) is established as promising for the organization of protected areas of local importance. It falls into the category of the protected natural landscape.

The results of the study show that the Lasvinsky lakes are a kind of water complex with specific hydrochemical and hydrobiological characteristics, which can be transformed into protected areas.

Table 2. Biological indicators of the water quality of Lasvinsky Lakes

Taxon	Zoobenthocenosis			
	Bolshoye Lasvinskoye Lake	Dikoe Lake	Maloye Lasvinskoye Lake	Lobkhanskoye Lake
Oligochaete Index	200/ low pollution	100/ low pollution	100/ low pollution	100/ low pollution
King-Ball Index	0.4 / dirty	1.0/ heavily contaminated	0.5 / heavily contaminated	0.8 / heavily contaminated
Goodnight-Whitley Index	22 / condition is good	33/ condition is good	23/ condition is good	30/ condition is good
Water Quality	*relatively clean*	*relatively clean*	*relatively clean*	*relatively clean*

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