

Ecological and Hygienic Assessment of the State of the Recreational Lake in the City of Ufa

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Abstract—Lake Kashkadan is one of the aesthetic and recreational sites of the city of Ufa. An assessment of the ecological and hygienic condition of the reservoir was made and a system of biotechnological and bioengineering measures to optimize the conditions of recreation was developed. It was revealed that according to physicochemical and sanitary-bacteriological indicators, the water in the lake corresponds to the standards for recreational water bodies. An unfavorable situation is observed in the parasitological indicators of water (viable lamblia cysts, eggs of ascaris, toxocara, fasciola and opisthorchis were found). The algological studies revealed 26 species of alga and cyanoprokaryotes of 4 clades (Bacillariophyta, Chlorophyta, Cyanophyta and Dinophyta). Moreover, these indicator-species of organic contamination account for 53.84% of the total taxonomic list. The largest number of alga and cyanobacteria belongs to β -meso-saprobionts. The saprobity index is 1.94, which corresponds to the β -meso-saprobic zone – the water is “slightly (moderately) contaminated”. Among the highest aquatic plants, the dominant feature is *Potamogeton lucens* L., which occupies about three quarters of the lake’s surface and forms a large biomass. The dominant elements in the coastal zone are *Typha latifolia* L. and *Typha angustifolia* L. Generally, the state of the ecosystem of Lake Kashkadan is characterized as relatively favorable. To maintain and improve the ecological and hygienic condition of the reservoir, two options for biotechnical measures can be considered: biotechnical measures with preservation of the lake bed and deepening of the lake bottom sections of 5-6 meters with the adoption of additional bioengineering and technical solutions. Preservation of the zone of aquatic plants thickets, arrangement of bathing area, construction of dog walking sites, maintenance of an adequate sanitary condition in the residential zone adjacent to the lake remains relevant for both options.

Keywords—recreational water area, sanitary and epidemiological safety, eutrophication, phytoplankton, bioindication.

I. INTRODUCTION

One of the factors determining the social attractiveness of residential areas is the arrangement of recreation zones. An important place among the objects of recreational use is occupied by intracity ponds, which have aesthetic appeal and health-improving value [1-5]. So, in a place, where asphalt and concrete surfaces dominate, aquatic complexes prevent uniformity, form a landscape that aesthetically satisfies, videoecological and socio-psychological needs of citizens. Ponds located within the walking distance allow metropolis’ residents to spend more time in the fresh air and contribute to

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outdoor activities. In addition, the presence of well-developed parks with ponds has a positive effect on the perception by the city guests of aesthetic, historical, cultural, environmental and recreational functions, contributing to creation of a positive image of the city and contributing to the development of regional and international tourism. At the same time, aquatic systems contribute to the improvement of the urban microclimate by absorbing solid pollutants, increasing air humidity and attenuating adverse thermal radiation in the hot season [6-7].

One of the factors determining the recreational attractiveness of water bodies is the sanitary-ecological state. Water quality, well-attended coastline, as well as biodiversity of flora and fauna are of great importance for modern man [4,8]. Deterioration in water quality may be caused by the entry of untreated wastewater into the water body, littering of the surface of the water area and coasts, eutrophication processes, and so on. With a decrease in the ability to self-purify, over time, the reservoir loses its recreational qualities and may become unsuitable for use. The most important indicator is the sanitary and epidemiological safety of the water body, since unsatisfactory water quality can pose a threat to public health, contributing to the development of massive infectious and parasitic diseases.

Periodic comprehensive studies of aquatic systems allows you to track negative processes and, if necessary, develop optimization management measures aimed at both preserving the quality of the reservoir and protecting public health.

The objective is to assess the ecological and hygienic state of Lake Kashkadan and to develop a system of biotechnological and bioengineering measures to optimize the conditions of recreation.

The Kashkadan Lake is located in the city of Ufa, in the right-bank high floodplain of the river Ufa (54°46’32” N and 56°03’30” E) and is an aesthetic and recreational object of urban infrastructure. Initially, it was a natural reservoir of old origin. By 2000, there was significant siltation of the lake and shallowing. In 2002, during the construction process, a new lake bed was formed on the shore of the reservoir of culture and recreation park. At the same time, the bottom was strengthened with waterproof clay, creating a “clay castle”. After the reconstruction, the connection with the Ufa River was lost and the power supply system of the lake was supplemented by pumping water from the river. Thus, we can assume that Kashkadan is now an artificial reservoir. Today, the length of the water body is 1020 m, the average width is

300 m, the average depth is 2.5 m. Private households are located on the north and west sides of the lake. The beach and boat station are equipped on the southern and eastern shores, as well as sports grounds and recreation areas. Recreation at a water body includes swimming, boating and catamarans, sunbathing and air bathing, fishing.

Since the reconstruction, the lake’s ecosystem has passed the stages of eutrophication and stabilization of the state at a level that meets the requirements for cultural and public water bodies. However, due to the accumulation of organic matter in the form of sludge and the strong heating of water due to its shallow depth, situations are not excluded when eutrophication processes can begin again.

II. RESEARCH METHODOLOGY

To assess the ecological and hygienic condition of Lake Kashkadan during the growing season of 2019, we carried out comprehensive studies, including physicochemical, sanitary-bacteriological and parasitological analysis of water, a study of the composition of alga, cyanobacteria, aquatic and coastal vegetation.

Water samples were taken in triplicate on May 14th and June 27th off the northern and eastern shores on different depths. Samples were analyzed in an accredited laboratory of the Center for Hygiene and Epidemiology of the Republic of Bashkortostan in accordance with approved methods [9-18]. Water quality assessment was carried out by comparing the results of the analysis with the standards [19-21].

The alga and cyanobacteria sampling points were located in the longitudinal and transverse directions of the lake on perpendicular transects (Fig. 1).

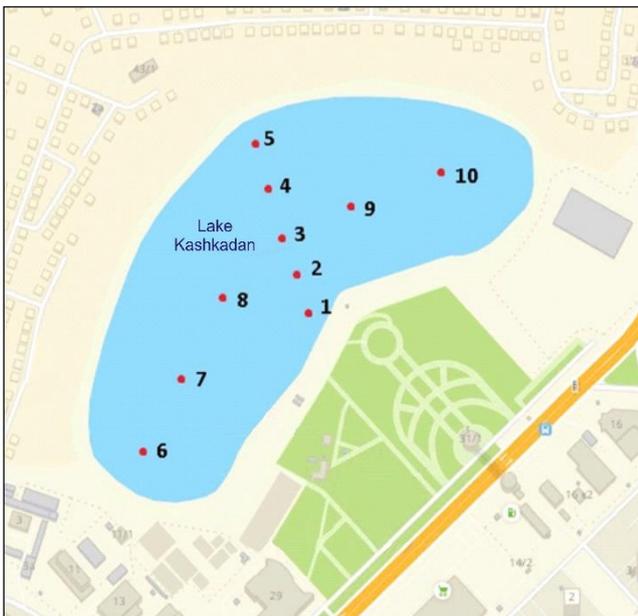


Fig. 1. Alga and cyanobacteria sampling points

Phytoplankton was selected with a 1 l Rutner bathometer. The samples were thickened by the sedimentary method; a 40% formalin solution was used to fix the obtained material. Quantitative calculations of phytoplankton organisms were carried out in a 0.01 ml Najott’s chamber using a light microscope. The study of phytoplankton and assessment of the reservoir by the composition of alga was carried out according to generally accepted methods [22]. For a

comparative assessment, the results of 2019 were compared with similar data for 2014-2015.

Coastal aquatic vegetation and flora were studied by the route method. Aquatic vegetation was studied from a boat during sampling of water and phytoplankton. Geobotanical descriptions were carried out according to generally accepted methods. To assess the abundance of species at the site, the J. Braun-Blanquet scale was used [23-24].

Based on the obtained data, the ecological status of the reservoir was assessed using bioindication methods.

III. RESULTS

Among the physicochemical parameters of water that we studied (Table I), nitrite ions, nitrate ions, and sulfides are the most significant. Nitrites act as an intermediate product of the biological oxidation of ammonia to nitrates. Nitrification processes are possible only under aerobic conditions, otherwise natural processes follow the path of denitrification – reduction of nitrates to nitrogen and ammonia. Compared to other nitrogen compounds, nitrates are the least toxic, but in significant concentrations cause harmful effects on organisms. The main danger of nitrates is their ability to accumulate in the body and oxidize to nitrites and nitrosamines, which are more toxic and can cause secondary and tertiary nitrate poisoning. The content of sulfides allows us to judge organic contamination, since hydrogen sulfide is formed during degradation of protein. These indicators in the water of Lake Kashkadan are within normal limits.

TABLE I. PHYSICAL AND CHEMICAL INDICATORS OF WATER QUALITY OF LAKE KASHKADAN

Indicator	Analysis results
Dissolved oxygen, mg/dm ³	8.10±1.30
Biochemical oxygen demand (BOD ₅), mgO ₂ /dm ³	0.67-3.40
Chemical oxygen demand (COD), mgO ₂ /dm ³	5.00-6.03
Nitrite ion, mg/dm ³	0.010-0.007
Nitrate ion, mg/dm ³	below 0.20
Sulfides, mg/dm ³	below 0.002
Phosphate ion, mg/dm ³	0.08-0.20
Total phosphorus, mg/dm ³	0.10-1.13
Total mineralization (solids), mg/dm ³	514.0±46.3
Hydrogen indicator, pH	8.08±0.20

The calculation of the water oxygen saturation degree showed that this indicator varies from 94.6% to 98.1% at different depths and in different parts of the lake. According to experimental and calculated data (the content of dissolved oxygen, the degree of water saturation with oxygen), the lake water belongs to the I-II quality class – from “very clean” to “clean”. According to the value of the biological oxygen demand for 5 days (BOD₅), lake water also belongs to the I-II quality class. The concentration of phosphate ions in the lake meets the standards for mesotrophic-eutrophic water bodies.

The results of bacteriological studies of water are presented in table II.

TABLE II. BACTERIOLOGICAL INDICATORS OF WATER QUALITY OF LAKE KASHKADAN

Indicator	Unit of measurement	Results	Permissible level
Pathogens of intestinal infections	-	Not detected in 1.0 dm ³	Absence in 1.0 dm ³
Coliphages	CFU/100 ml	0	10
Common coliform bacteria	CFU/100 ml	60	500
Thermotolerant coliform bacteria	CFU/100 ml	60	100

As it can be seen from Table II, intestinal infections and coliphages were not detected in water samples. The content of total coliform and thermotolerant coliform bacteria is below the permissible level. Therefore, the bacteriological situation on Lake Kashkadan can be considered safe.

Results of a parasitological study of water indicate an unfavorable situation at the research object. So, the viable giardia cysts (80 units/m³), viable ascaris eggs (50 units/m³), toxocara eggs (20 units/m³), fasciola eggs (2 units/m³) and opisthorchis eggs (1 units/m³) were found in the water samples. According to official data from the regional Office of Rospotrebnadzor (the Russian Federal Service for Surveillance on Consumer Rights Protection and Human Wellbeing), inconsistency in parasitological indicators is recorded periodically in the summer months in the water samples from Lake Kashkadan.

One of the important components of aquatic ecosystems is algae and macrophytes, which determine primary production and open food chains. The composition and structure of vegetation determine the diversity and productivity of the heterotrophic biota of the reservoir. In 2019, we identified 26 species of alga and cyanoprokaryotes in Kashkadan Lake belonging to 4 clades: Bacillariophyta, Chlorophyta, Cyanophyta and Dinophyta. Figure 2 shows the comparative taxonomic characteristics of phytoplankton of Lake Kashkadan in 2014, 2015, and 2019.

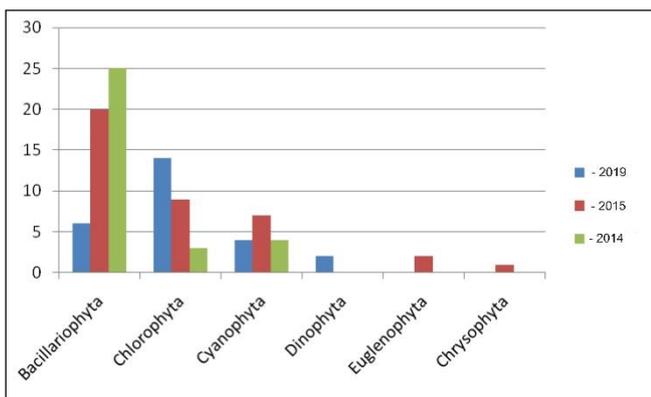


Fig. 2. Taxonomic characteristics of phytoplankton of Lake Kashkadan in 2014, 2015 and 2019

The greatest species richness was noted in the Chlorophyta clade (53.85% of the total number of species). The clade was represented by 4 classes, 7 orders, 10 families, 12 genera and 14 intraspecific taxa. Representatives of the Bacillariophyta department accounted for 23.08% of the total number of species and were represented by 2 classes, 4

orders, 4 families, 5 genera, and 6 intraspecific taxa. The Cyanophyta clade was represented by the 1 class of Cyanophyceae, 3 orders, 3 families, 4 genera, and 4 intraspecific taxa (a total of 15.38% of the total number of species). Representatives of the Dinophyceae clade accounted for 7.69% of the total number of species.

Among higher aquatic plants, the absolute dominant is the shining pondweed (*Potamogeton lucens* L.), which occupies about three quarters of the lake's surface and forms a large biomass. Of the other submerged macrophytes, the sago pondweed (*Potamogeton pectinatus* L.) is occasionally and singly found. Among the submerged benthic plants in all parts of the lake, the hornwort (*Ceratophyllum demersum* L.) is found, but it does not form large thickets. Of the attached plants with floating leaves, a white water lily (*Nymphaea alba* L.) and a yellow water lily (*Nuphar lutea* (L.) Smith) are densely found and in plentiful amount.

Absolute dominants in the coastal zone are broadleaf cattail (*Typha latifolia* L.) and narrowleaf cattail (*Typha angustifolia* L.), which form dense thickets along the western shore of the lake. Cosmopolitan common reed (*Phragmites australis* (Cav.) Trin. Ex Steud.) and lakeshore bulrush (*Scirpus lacustris* L.) are also found as the air-water macrophytes. Along the coastline, species such as purple loosestrife (*Lythrum salicaria* L.), roundfruit rush (*Juncus compressus* Jacq.), creeping bentgrass (*Agrostis stolonifera* L.), and common spike-rush (*Eleocharis palustris* (L.) R. Br.) are densely found.

The dominant features on the gravel areas of the beach are Dutch clover (*Amoria repens* (L.) C. Presl) and broadleaf plantain (*Plantago major* L.). The dominants of tinned southern and western shores are meadow fescue (*Festuca pratensis* L.), Dutch clover (*Amoria repens* (L.) C. Presl), silverweed (*Potentilla anserina* L.), broadleaf plantain (*Plantago major* L.) and perennial ryegrass (*Lolium perenne* L.) (which was sowed). More than 70 species of vascular plants in total were recorded on the lake and in the coastal zone. The projective cover of vegetation on the eastern and southeastern shore (beach) is 15-30%, on the western shore – up to 100%.

It is a fact that environmental monitoring by using bioindication methods allows obtaining more objective data on the state of the aquatic ecosystem [25-26]. A sensitive indicator of the state of water bodies is phytoplankton. For example, alga play a leading role in indicating changes in water quality as a result of eutrophication. Ecological and geographical analysis of phytoplankton samples of Lake Kashkadan showed that the bulk of the recorded alga is widespread in continental water bodies (cosmopolitan species). Organic indicator species comprise 53.84% of the total taxonomic list of alga and cyanobacteria. The greatest number of alga and cyanobacteria belonged to β-meso-saprobionts. When calculating the numerical value of the saprobity index, the indicator was 1.94, which corresponds to the β-mesospar-like zone (purity class III) – the water is “slightly (moderately) contaminated”. In 2014-2015, indicator species of organic contamination accounted for 51% of the total taxonomic list of alga recorded in the lake. The largest amount was attributed to oligo-α-meso-saprobionts.

According to the results of laboratory tests, the lake, according to various indicators, refers on average to the oligo-

β -mesosaprobic zone. Xenosaprobity for individual indicators is the result of oxygen saturation of water (aeration by fountains, oxygen evolution by a mass of macrophytes). In the northeastern part of the lake, the deepest sections belong to the α -meso-saprobic zone, which, in our opinion, is associated with an increased concentration of phosphates. Large differences in the concentration of total phosphorus (more than 13 times) in individual sections of the lake suggest that not everywhere the element is equally involved in the biological cycle or is fixed by aquatic organisms. It is well known that the main fixators of phosphorus in reservoirs are the higher aquatic plants, and in the north-eastern part of Lake Kashkadan there are no thickets of macrophytes.

A survey of the territory adjacent to the lake revealed that a significant part of the nutrients enter the water body with surface and ground runoff from the residential area with private households, where there are unauthorized landfills for household waste and unequipped cesspools. An increased concentration of nutrients (nitrogen and phosphorus) during water heating in the summer period can lead to water "blooming" and to clogging phenomena. However, as the results of bioindication showed, the present issue of eutrophication of a reservoir is not acute.

IV. SUGGESTIONS

Conducted comprehensive studies suggest that, in general, the state of the ecosystem of Lake Kashkadan is relatively good. Nevertheless, in order to maintain and improve the ecological and hygienic condition of the reservoir, a number of measures are necessary. So, in order to improve water quality by parasitological indicators, it is necessary to regulate the dog walking activity in the coastal zone with the allocation of specially equipped sites, as well as observe sanitary standards for keeping dogs in the private sector, since the main source of contamination with cysts and parasite eggs is the dogs' feces. In addition, the elimination of unauthorized landfills, control over the arrangement of cesspools and the maintenance of domestic animals are necessary.

To prevent overgrowing of the swimming area with aquatic macrophytes, it is necessary to clean the lake bottom with a dredger and fill it with gravel. The arrangement of bathing areas will prevent the growth of aquatic vegetation. In the remaining parts of the lake, macrophytes act as stability factors in the favorable sanitary condition of the lake, being sources of oxygen, suspended solids, accelerators of self-cleaning processes and detoxifiers of harmful substances. Catamarans can be organized in a specially allocated deeper north-eastern part of the lake, devoid of thickets of aquatic plants.

Subject to the above recommendations, the need for the reconstruction of the reservoir in the coming years will not arise. Nevertheless, in order to maintain the ecological state of the lake in the future, it may be necessary to deepen it. When deepening Lake Kashkadan, possible negative consequences should be taken into account. Thus, when a water body is deepened of 5-6 meters, a zone free of macrophytes is created, which will entail a decrease in dissolved oxygen in the warm season and an increase in the concentration of nutrients. Due to the lack of water movement, the process of "blooming" in the upper warmed water layer may begin, followed by the death and subsidence of planktonic organisms due to oxygen deficiency in the dark

areas. The accumulation of organic matter and lack of oxygen will lead to anaerobic processes, which are accompanied by the formation of methane, carbon monoxide, hydrogen sulfide, ammonium nitrogen. The resulting toxic protein breakdown products will give the water an unpleasant putrescent odor.

At the same time, the deepening of the lake entails a number of positive aspects. Firstly, the buffer capacity of the reservoir increases, and when nutrients enter, their concentration will increase at a slower rate. Secondly, the temperature regime is stabilized and the likelihood of overheating of the reservoir, which contributes to the "blooming" of water, will decrease. Thirdly, the linear deep channel will accumulate the current of bottom sediments, and this, in turn, will facilitate the possibility of biological and mechanical treatment of the reservoir. To achieve such positive processes, certain conditions must be created. Firstly, water aeration is required to increase dissolved oxygen and inhibit anaerobic processes. The most effective will be aeration during the arrangement of several fountains along a deep channel and water intake in the bottom layer. Fountains will provide water circulation in the transverse direction from the coast to the center of the reservoir. Secondly, it is necessary to ensure the flow of the lake in the longitudinal direction by combining fountains with flow-forming agents. The near-bottom direction of the flow will facilitate the circulation of water in the deep channel with its saturation with oxygen and the formation of suspended sediment. Puffed sludge in oxygenated water will be subject to rapid aerobic decomposition with the participation of microorganisms. In addition, ensuring a longitudinal flow of water will optimize the number of fountain aerators to the minimum required number. Thirdly, at least one third of the water body area must be left in its existing state with the prevailing diversity of biota, mainly the aquatic plants. Macrophytes contribute to the water saturation with oxygen, are the nuclei of a consortium of many aquatic organisms (bacteria, alga, protozoa, aquatic invertebrates) that create and support the self-purification of the aquatic ecosystem. In addition, aquatic plants precipitate suspended solids and fix nutrients. Preservation of the zone of coastal-aquatic and aquatic vegetation (cattail, bulrush, reed, water lilies) is also necessary to fulfill the barrier function on the path of inflow of nutrients from the residential zone with private farmsteads. The swimming area should be equipped taking into account the obstacle for the growth of aquatic vegetation or its' easy removal. This can be ensured by arranging the bottom with a sand-gravel mixture of sufficient power (30-40 cm) with a finest fraction.

The proposed time limit for the reconstruction of the lake with a deepening is the October-November. The choice of this time period is due to the fact that this will preserve the viability of sprouts (rhizomes, roots, seeds) of aquatic plants, protecting them from drying out or freezing. The preservation of viable sprouts will ensure their growth in the next season with a complete restoration of the functions of biological treatment of the reservoir. It is necessary to clean the lake from bottom sediments at least once every five years in the future.

V. CONCLUSIONS

We conducted comprehensive studies that allowed us to assess the ecological and hygienic state of Lake Kashkadan and to develop a system of biotechnological and

bioengineering measures to optimize the conditions of recreation. It was discovered that the water quality according to physico-chemical and sanitary-bacteriological indicators corresponds to the standards for recreational water bodies. The unfavorable situation at the research object is observed by parasitological indicators, which is associated with dog walking activity in the coastal zone, non-compliance with sanitary requirements pet keeping in the private sector, the presence of unauthorized landfills and undeveloped cesspools in households located in the immediate vicinity.

Algoflora of Lake Kashkadan is represented by 26 species of alga and cyanoprokaryotes, belonging to 4 clades (Bacillariophyta, Chlorophyta, Cyanophyta and Dinophyta). Indicator-species of organic contamination comprise 53.84% of the total taxonomic list. The largest number of alga and cyanobacteria belongs to β -meso-saprobionts. The saprobity index is 1.94, which corresponds to the β -meso-saprobic zone (purity class III) – the water is “slightly (moderately) contaminated”.

More than 70 species of vascular plants were recorded in total in the lake and in the coastal zone. Among higher aquatic plants, the absolute dominant is the shining pondweed (*Potamogeton lucens* L.), which occupies about three quarters of the lake’s surface and forms a large biomass. Absolute dominants of the coastal zone are broadleaf cattail (*Typha latifolia* L.) and narrowleaf cattail (*Typha angustifolia* L.), which form dense thickets along the western shore of the lake. The projective cover of vegetation on the eastern and southeastern shore (beach) is 15-30%, on the western shore – up to 100%.

In general, the state of the Lake Kashkadan’s ecosystem is characterized as relatively favorable. In order to maintain and improve the ecological and hygienic condition of the reservoir, two options for biotechnological measures can be considered. The first option is to conduct biotechnological activities while preserving the bed of the lake. The second option is to deepen sections of the lake bottom of 5-6 meters with the adoption of additional bioengineering and technical solutions.

For both options, it remains relevant:

- preservation of the zone of thickets of aquatic plants;
- arrangement of the swimming area;
- construction of a dog walking site;
- maintaining good sanitary conditions in the residential area adjacent to the lake.

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