Use of higher aquatic vegetation for post-treatment of wastewater

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Abstract. The article presents the features of cascade phyto-treatment facilities, bio plateau with an open water mirror. Such structures are similar to natural wetland objects. The plant species on the cascades and their effect in the post-treatment of wastewater are considered. Natural biological treatment of wastewater with algae roots is one of the most effective methods of treatment. This method allows you to clean polluted wastewater without harming the environment. Aquatic plants intensify the purification process, remove biogenic elements, actively using them in their nutrition, remove heavy metals and organic substances from the water and accumulate in the root system, which are difficult to decompose and thus improve the process of self-purification of reservoirs. The article pays great attention to the project «The Resilient Ribbon: A Timeless Legend of Kazan». The essence of the project is the natural self-purification of the city lake Nizhny Kaban in Kazan, where the root system of plants is used to purify water from mixtures, phenols and phosphates, heavy metals and a number of other harmful substances. The results of laboratory studies of water quality after treatment at cascade phyto-treatment facilities are presented.
Keywords. Phyto-treatment facilities, bio plateau, higher aquatic vegetation, cascade, plants, Kaban lake.

1 Introduction

In recent years, biological ponds, bio plateaus with an open water mirror and artificially created phyto-treatment facilities have become widespread. Such structures are similar to natural wetland objects [1, 2]. They have a number of technical elements that are built into the natural landscape and are water treatment systems.

There are the following designs of bio plateaus: surface, infiltration and surfacing. Artificially created bio plateaus with an open water mirror are used for wastewater treatment, where the highest aquatic vegetation is used: iris, cattail, iris, pondweed, lake reed, sagittaria and others. Here, the planting density is usually 1-15 plants per 1 m^2. The bio plateau is filled with water to a level of 0.3 to 1.5 m, and the flow rate is 0.005-0.01 m/s [3, 4].

The following bio plateau designs have been developed: single-tier, double-tier, single-stage and multi-stage, which make it possible to carry out effective cleaning, as well as to remove the treated water into the groundwater stream or directly into the reservoir.

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A bio plateau with a container planting method in the presence of microorganisms purifies water better, and after ultra-violet radiation, the efficiency of purification from radio cesium ions by sugar corn plants increases. For the climate zone of the middle zone Russia was offered a combined floating bio plateau [5–9].

Phyto-treatment facilities of artificial origin with a specific composition of microorganisms are considered. Microorganisms develop in the root zone of plants that are in an aquatic environment. In such biological ponds, bio plateau and phyto-treatment facilities, various water crops are planted according to a certain scheme – reeds, lake reeds, narrow-leaved and broad-leaved cattails, water hyacinth (eichornia), stratiotes, combed and curly pond grass, myriophyllum, stonrwort, iris, sea rhesus, yellow iris, microalgae and others [10, 11].

The aim of the study is to determine the effect of post-treatment of wastewater, with the help of phyto-treatment facilities of reservoirs of recreational zones, from various types of pollution.

2 Materials and methods

Microalgae present in water can accumulate plant nutrients, heavy metals, pesticides, organic and inorganic toxic substances, and radioactive substances in their bodies [12].

Phyto-cleaning is often done using water hyacinth-eichoria. Hyacinth is crucial for the biological recovery of nitrogen [13, 14].

Aquatic plants can reduce eutrophication and increase phytoplankton diversity, thereby providing guidance for the restoration and protection of aquatic ecosystems, as excess phosphates in water leads to algae growth or eutrophication [15–19].

The elimination of heavy metals can also be performed on the roots of two plants belonging to the Poaceae family (Arundo donax and Phragmites australis). At the same time, the concentration of COD, BPK5, phosphates, nitrates and electrical conductivity decreases [20].

Aquatic plants intensify the purification process, remove biogenic elements, actively using them in their nutrition, remove from the water and accumulate heavy metals and organic substances that are difficult to decompose, such as radioactive isotopes and other specific contaminants. During photosynthesis, water is enriched with oxygen, and plants are able to accumulate toxic substances and convert them into non-toxic ones [21].

To a greater extent, phyto-treatment plants are built in Germany, the United States, Australia and in the Nordic countries. Phyto-treatment plants are mainly used for the treatment of household, surface, and waste water of the food industry, livestock complexes, and a number of other waters. In the world, photo-treatment plants are recognized as the best available facilities, and thanks to their implementation, the water quality in small rivers of small settlements has improved significantly, especially in Europe. In the United States, mine water treatment systems are widely used on reed and reed plantations. There are phyto-treatment plants for the treatment of domestic wastewater with reed vegetation in Japan, the Netherlands, China, and for the treatment of surface wastewater in Australia, Norway. In the UK, reed phyto-treatment plants are used to treat the wastewater of pig farms, as the reed is resistant to the action of large concentrations of pollutants. Water hyacinth in China is used to clean the sewage of a film factory from silver.

Reeds and cattails remove nitrogen from wastewater and reduce biological oxygen demand. The effectiveness of reducing the biological oxygen demand was the highest in reeds, slightly lower in reeds and cattails. Biologically purified water passing through the root system and reed beds is released from viruses into the bio pond on the third or fifth day [22].

The cattail root system has a high adsorption capacity with respect to heavy metals. The concentration of metals in the root system of cattail, which grew on the banks of sludge accumulators of power plants, was: iron – 199.1 mg/kg; manganese – 159.5 mg/kg; copper – 3.4 mg/kg; zinc – 16.6 mg/kg.

Based on the location of the hydraulic design line, as well as the direction of the flow of moving water of phyto-treatment facilities, it has four main types: with a free water surface; with a horizontal subsurface flow; with a horizontal subsurface flow and combined.

Available phyto-treatment facilities are classified: by the movement of the water flow; by the type of filter and feed material; by the type of artificial plant community.

Gravel, sand, soil, peat, and a combination of these materials are used as filter and feed materials.

As an artificial plant community, the following are used: mono-or poly-culture, native species, or imported, floating or fixed plants.

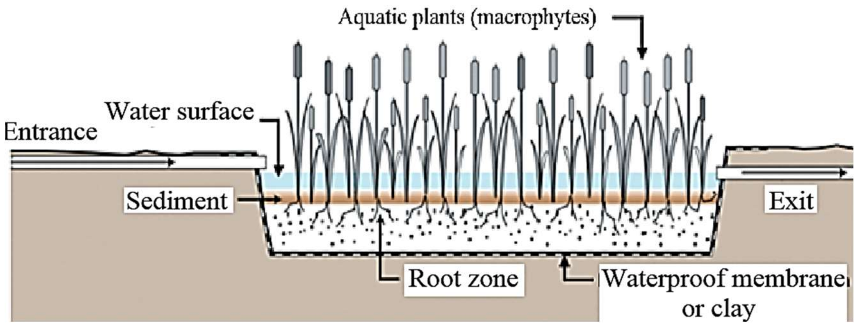

Fig. 1. PTF with a free water surface.

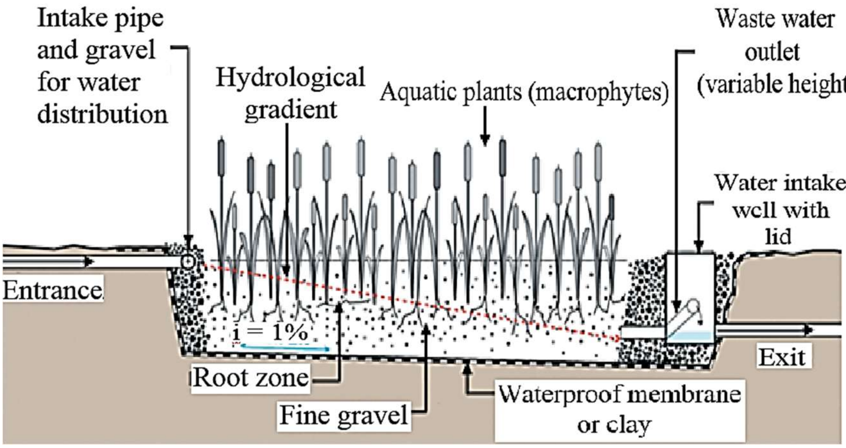

Fig. 2. PTF with horizontal subsurface flow.

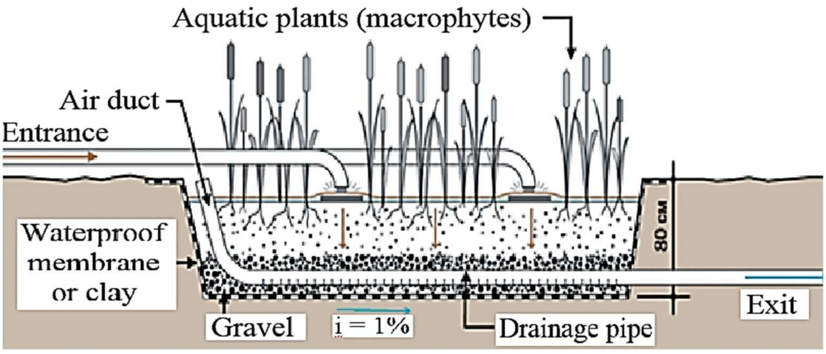

Fig. 3. PTF with vertical under surface flow.

Subsurface phyto-treatment plants are the most common in Europe. Currently, combined phyto-treatment plants, as well as phyto-treatment plants with various engineering structures, have become more often used to improve the process of water aeration, to regulate the retention time of wastewater in cascades, if necessary, to redirect the flow of water, etc. Forced aeration is one of the best techniques for increasing the cleaning effect.

3 Results and discussion

In connection with the discharge of untreated wastewater from many nearby enterprises, CHPP-1, surface wastewater became unsuitable for recreation, swimming, etc. It was necessary to clean the waters of the lakes. So, a competition was announced to develop a concept for cleaning the Kaban lakes. Based on the results of the competition, the cascade phyto-treatment facilities «The Resilient Ribbon» were adopted for the cleaning of Kaban Lakes. «The Immortal Legend of Kazan» by the Russian-Chinese consortium Turenscape + MAP architects.

The nitrate content in the Lower Kaban Lake according to the results of the 2013 studies is 41.3 *mg/l*, while the MPC is 40 *mg/l*. The increased content of nitrates in natural waters is not safe. Thus, their accumulation in open reservoirs leads to the growth of algae and bacteria, which leads to a decrease in the content of oxygen dissolved in water and the death of aquatic fauna.

Nitrites in the Lower Kaban Lake are 0.0128 *mg/l* according to the MPC of 0.08 *mg/l*. The amount of nitrites is normal.

The content of phosphate ions in the lake is 0.23 *mg/l*, which exceeds its content according to the MPC, which is 0.05 mg/l. The increased content of phosphorus in the water leads to increased eutrophication, an increase in the number of blue-green algae, which negatively affects the ecosystem of the water body.

All results of laboratory tests of water quality for 2013 are included in Table 1.

Table 1. Results of laboratory tests of water quality for 2013.

Indicators, units of measurements	Research results	MPC standards
pH, units	8.5	6.5-8.5
Chromaticity, ° chromaticity	39.8	20
Colour	green	
Turbidity, *mg/l*	14.98	1.5-2
Hardness, W °	8.8	7-10
Water temperature, C °	21.2	
Oxygen, *mg/l*	9	not less than 4
Ca, *mg/l*	119	180
Mg, *mg/l*	10.6	40
NH_4, *mg/l*	0.33	0,5
NO_2, *mg/l*	0.01	0,08
NO_3, *mg/l*	41.3	40
PO_4, *mg/l*	0.23	0,05
Mineralization, *mg/l*	58	1000
Petroleum products, *mg/l*		0,05

The goal of this project «The Resilient Ribbon: A Timeless Legend of Kazan» is natural self-purification of the Kaban lakes of Kazan.

The main task of cleaning the Lower Kaban Lake will be taken over by plants that will purify the water from suspension, mixtures, phenols and phosphates, heavy metals, from harmful substances of galvanic production and a number of other harmful substances. Wastewater from galvanic production can be treated using galvanic coagulators [23]. Methods for purifying water from surface sources from suspended matter are detailed in the article [24]. Before that, such a system of water purification with the help of plants in Russia was rarely used. The phyto-treatment facilities of the Lower Kaban Lake are located on several tiers. Water is supplied to the facilities through a 15-meter channel. Waste water, passing through a system of water cascades with planted plants, is fed to Kaban Lake purified. The system consists of eight and five stages.

Consider the largest system of phyto-treatment facilities, namely, of 8 cascades. The first cascade receives water from the Lower Kaban Lake. In the first one, water hyacinths work, which grow very quickly in the sun and are cleaned thanks to the roots of the plant, which reach a length of about a meter. Microorganisms that filter all the water passing through them live on the roots of plants, that is, they take all the harmful toxic substances contained in Lake Kaban.

Fig. 4. First cascade: water hyacinths.

Then the partially purified water flows into the second cascade. In the second cascade, water reeds grow. Reed is considered the best purifier of lakes and rivers in central Russia. Reeds destroy phenols, hundreds of heavy metals, and organic mineral substances.

Fig. 5. Second cascade: water reed.

Then the waste water enters the third cascade, where the loosestrife is planted. Then the water flows into the fourth cascade with cattail narrow-leaved.

Fig. 6. Third cascade: loosestrife.

Fig. 7. Fourth cascade: narrow-leaved cattail.

In the fifth cascade, marsh irises grow, and in the sixth channel, a decorative mannikin grows, which will grow to a height of 1.5 meters.

In the seventh cascade, the Tatar grass calamus grows. In ancient times, the nomadic Tatars always carried the roots of this plant with them, and if they did not find it in a new place, they planted it all over the pond. As a result, the water was purified to the quality of drinking water.

Fig. 8. Seventh cascade: tatar grass calamus.

In the eighth cascade with water lilies flows relatively clean water. Lily leaves quickly rise to the surface. Here you can immediately see how the water quality has changed: it becomes transparent.

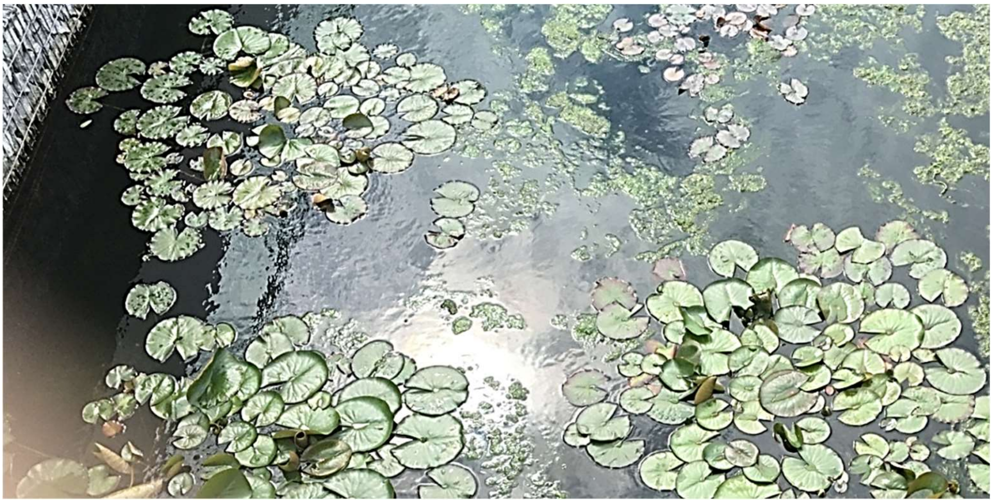

Fig. 9. Eighth cascade: water lilies.

A full cycle of water purification will take from one to two days. Each stage has sensors for basic chemical parameters: oxygen, temperature, pH, as well as nitrogen and phosphorus content.

The main eutrophying elements for freshwater reservoirs are phosphorus and nitrogen. The sources of these elements in the Lower Kaban Lake are surface runoff and direct discharge of industrial wastewater, storm water runoff from urbanized areas.

All results of laboratory tests of water quality for 2020 are included in Table 2.

Table 2. Results of laboratory tests of water quality for 2020.

Indicators, units of measurements	Research results	MPC standards
pH, units	7.96	6.5-8.5
Chromaticity, ° chromaticity	9.58	20
Colour	Transparent, light yellow	
Turbidity, *mg/l*	2.56	1.5-2
Hardness, *W*°		7-10
Water temperature, *C*°	16.1	
Oxygen, *mg/l*	5.76	not less than 4
Ca, *mg/l*	60	180
Mg, *mg/l*	7	40
NH_4, *mg/l*	4.58	0.5
NO_2, *mg/l*	0.61	0.08
NO_3, *mg/l*	0.939	40
PO_4, *mg/l*	0.11	0.05
Mineralization, *mg/l*	1100	1000
Cl, *mg/l*	100	300
Petroleum products, *mg/l*	0.012	0.05

4 Conclusion

As a result, on the basis of experiments and the construction of natural biological phyto-treatment facilities on Lake Nizhny Kaban, it was found that the best facilities for the treatment of highly polluted wastewater are natural biological photo-treatment facilities for the treatment of wastewater with algae. The root system of algae adsorbs pollutants and on the basis of this, self-purification of Lake Kaban in the city of Kazan, Republic of Tatarstan takes place. For the full recovery and restoration of the Kaban lake system, it is necessary to ensure the constant flow of all three Kaban lakes and channels, connecting them with the Kazanka River and the Volga River, or constant aeration of the water in the lake.

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