Efficiency of phytoredomedia methods in water disposal

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Abstract. The paper reflects the results obtained from the studies on hydro-botanical waste-water facilities conducted to treat waste-water at the sewage facilities located in the Andropovsky District of the Stavropol Region and intended for biological treatment of industrial and domestic waste-water. As a result of the studies within 2016–2018, it was found that during the exploitation time the content indicators of ammonium nitrogen and iron have decreased by 3 times, oil products and nitrates by 2 times, nitrites by 6.4 times, and phosphates by 8.5 times. The pH indicator reached the standard, which is important enough for water inlets since low pH without cleaning is destructive for most bio-organisms in aquatic ecosystems. The analysis of the hydrochemical indicators at the outlet in the water intake facility allows coming to a positive conclusion about the possibility of using phytoremediation methods for production and domestic waste-waters.

1. Introduction

Currently, much attention is paid to the quality of water resources in Russia. Water bodies are one of the main “storages” of pollutants since industrial and domestic effluents contain a wide range of toxic substances and compounds that have a detrimental effect on all bio-organisms and human health. For this reason, the requirements for the use of various waste-water treatment methods are increasing. There are many approaches solving this problem, one of which is the development and implementation of biological methods for waste-water treatment and purification. Some authors assume that the phytoremediation methods based on the use of higher aquatic vegetation are an environmentally effective approach of treating waste-water from a number of contaminants [4, 6]. Higher aquatic vegetation is used to create some special facilities.

It has been established that among the representatives of the macrophyte group there are used such plant species as combed and curled (Potamogeton pectinatus and Potamogeton crispus), reed (Phragmites), cattail (Typha), bulrush (Scirpus), duckweed (Lemna), and eledea (Elodea), Eichhornia (Eichhornia crassipes) or water hyacinth. Avicennia marina (Avicennia marina) is known to be used to create hydro-botanical facilities in order to reduce heavy metal pollution. To treat the contaminated surface groundwater in Kuwait, rotting of the leaves and roots of the reed (Phragmites australis) was used. T. Chrismadha et al suggested using the capabilities of the shallow Ryaska (Lemna perpusilla Torr.) to restore the ecologically disturbed state of the lake water [2, 3, 7, 8]. When assessing the effectiveness of this biological method of waste-water treatment and purification, it is necessary to take into account the period during which the processes of biota self-regulation of hydrobotanical facilities are shaping. Rich biocenoses of biological ponds can almost completely remove residual amounts of many compounds, neutralize pathogenic microflora. The analysis of foreign literature shows that the market for the phytoremediation technologies is actively growing and developing. Founded in 1983, Lemna Technologies, Inc. develops and markets the phytoremediation
technological waste-water treatment cycles in a wide range of choice, from private farms to medium-sized enterprises. In 1990, the company implemented a duckweed purification system at Devil Lake in North Dakota over an area of 25 hectares. The system was designed to extract nitrates and nitrites, ammonium sulfates from water, and reduce the number of colibacilli. To collect the waste duckweed, special floating combines were designed and constructed. In 1995, the company successfully tested rhizofiltration technologies for ground and surface water treatment in Ashtabula, Ohio, as well as small ponds near the Chernobyl Nuclear Power Plant. These field studies have shown the high efficiency of rhizofiltration in the purification of waters contaminated with the radionuclide. According to the data of A. Worku, N. Tefera, H. Kloos, S. Benor, hydrobotanical facilities for phytoremediation of industrial waste-water in Addis Ababa (Ethiopia) have been created in modern conditions. P. Saha, A. Mondal, S. Sarkar experimentally showed that about 95% of cyanide removal from blast water can be achieved with aqueous hyacinth in 3 days in 6 liters, as well as in 100 liters of water. Water hyacinth is also effective in reducing biochemical oxygen demand (BOD) and chemical oxygen demand (COD) [10, 11]. A hydroponic method is proposed for purifying livestock waste-water from nitrogen and phosphorus using a hydroponic cultivation system, a Rami terrestrial fibrous agro-plant. This technology allows exponentially increasing the number of high-quality seedlings for subsequent field cultivation and, accordingly, increasing the efficiency of waste-water treatment. Successful experience has been gained in applying the phytoremediation technologies even in northern latitudes: in Denmark (130 facilities), Sweden and Norway (71), Canada (67) and North America (600). Here, bio-plates have been successfully created and are being operated, which fulfill the function of waste-water treatment facilities [1, 5, 9].

2. Methods and materials
The studies were conducted within 2016-2018 at the waste-water facilities of the Andropovsky district of the Stavropol Region, which are intended for biological treatment of industrial and domestic waste-water. The purpose of the research was to assess the efficiency of phytoremediation technology in the waste-water system with the aim of post-treatment of industrial waste-water. During the research, we set up the following tasks to perform: to assess the state of the waste-water intake; to evaluate the operational efficiency of waste-water treatment facilities by using waste-water treatment facilities for post-treatment. A complete analysis was carried out once a month for the following indicators: temperature, the color of the reaction medium, pH, BOD5, COD, ammonium nitrogen, nitrates, nitrites, phosphates, surfactants, fats, oil products, chlorides, sulfates, solid residue, dissolved oxygen iron. The mass concentration of dissolved oxygen and sulfates in the waters was determined by the titrimetric method, the concentration of the sum of anionic synthetic surfactants in the waters was measured by the extraction-photometric method; the biochemical oxygen consumption in the waters was determined by the flask method. The obtained indicators were compared with the maximum permissible indicators of fishery value (MPC of fish). Sampling was carried out per under GOST 17.1.5.05. The mass concentration of dissolved oxygen in the samples of surface water and treated waste-water in the range of 1.0–15.0 mg/dm³ was determined according to the method developed by the hydrochemical institute, Scientific-production enterprise "Aquatest", certified by following GOST R 8.563 (GOST 8.010).

3. Results
The hydrochemical mode of rivers is fraught with regular changes in the chemical composition of water, some individual components over time that are explained with the physical and geographical conditions of the basin, as well as anthropogenic impact. In the course of the research, the analysis of the natural waters of the Kursavka River was conducted. These rivers serve as the water intake of the sewage treatment facilities. During the study, water samples with slightly alkaline pH values were noted; the highest concentrations of suspended solids were obtained in July, which may be associated with the increase in the amount of dead organic matter. The difference in solid matter in spring was 42mg / liter. The oxygen concentration is traced, which is associated with the processes of its intake
and consumption in the aquatic ecosystem. The oxygen content in the studied natural waters ranged from 7.7–10.7 mg/liter, which is a favorable factor, since for fishery reservoirs the concentration of dissolved oxygen in summer should not be lower than 6 mg/liter. The indicator BOD5 during the research period indicates a high content of easily oxidized organic substances. The maximum values were noted in April during the flood period, which is primarily associated with the entry into the water disposal of allochthonous organic substances from the catchment area. The indicators of permanganate oxidizability correspond to physical and geographical zonality, oxidizability is defined as average. Studies on non-organic indicators of water disposal were carried out with the focus on a set of factors and conditions that take part in the formation of the hydrochemical mode of natural waters (Table 1).

Table 1. Non-organic substances in natural waters of the water intake (average values for 2016–2018)

| Indicator, (mg/l) | March-May | June-August | MPC (mg/l) |
|------------------|-----------|-------------|------------|
| Ammonium-ions    | 0.72      | 0.54        | 0.5        |
| Nitrate-anion    | 3.12      | 0.54        | 40         |
| Nitrite-anion    | 0.20      | 0.24        | 0.08       |
| Sulfate-ion      | 293.0     | 228.13      | 100        |
| Chloride-ion     | 124.75    | 134.71      | 300        |
| Phosphate-ion    | 0.059     | 0           | 0.05       |
| Iron             | 0.20      | 0.26        | 0.10       |

The excess of sulfates averaged 2.4 MPC, for ammonium nitrogen – 1.4 MPC. A slight increase in the maximum permissible concentration (MPC) of phosphates was noted from 1.2 in March and May to 2.6 in July. The presence of phosphates in the waters of the river is due to both the processes of transformation of organic substances and the influx with waste-water. The iron content in the studied samples was 3.6–2.6 MPC in summer, 2 MPC in spring. Iron is a heavy metal and its excess can hurt harm the inhabitants of the aquatic eco-system. Along with this, iron is an important trace element, on which various biological processes depend. The intensity of phytoplankton development, as well as the quality of microflora in water bodies, depends on the iron content. The analysis of the season dynamics of the hydrochemical parameters of the water entering the treatment facility showed an excess of ammonia nitrogen from 35.4 MPC to 52 MPC of fish, the maximal value of nitrates amounted to 5.4 MPC in March and the minimal one was equal to 3.8 MPC in February. For sulfates, the value was not stable, within 1.8 to 2.7 MPC, and for phosphates from 1.5 to 5.7 MPC. In the studies, an excess of MPC for iron was noted. Since iron belongs to heavy metals, an analysis was made of the season indicators of this substance in the waters of the river where the water intake is (Fig. 1). The maximum values were recorded in September, which amounted to 4.9 MPC, the minimal indicators were recorded in spring, which amounted to 1.8 MPC.

Assessment of the effect of waste-water on the waters of the river with the water intake before applying the phytoremediation methods showed an excess of the MPC for biochemical oxygen consumption by 1.1–2.5 times, which is an indirect indicator of pollution by organic substance, on
dissolved oxygen averaged 2.5 MPC, on a solid residue of 3 MPC. Table 2 presents the data on the content of non-organic compounds in samples of river waters taken 500m below the discharge.

![Figure 1. Season dynamics of indicators of iron in the waters of the river intake](image)

The flow of nitrites into the river water ranged from 3.2 MPC to 2.1 MPC, the maximum indicator for excess sulfates was 3.5 MPC. The maximum phosphate content in the waters of the river with the water intake, when mixed with waste-water, was 13.6 MPC in November, and the minimum 2 MPC was in April. The analysis results, on the iron content in the river waters below the sewage discharge, indicate an excess of MPCs by almost three times in summer. Indicators of treated waste-water characterize the level of efficiency of treatment facilities using the phytoremediation methods (Table 3). To create hydrobotanical facilities the water hyacinth (eichornia) was used.

Table 2. The content of non-organic substances in the waters of the river with the water intake in samples of the waters of the river taken at 500m below the discharge.

| Indicator (mg/l) | April | July | November | MPC |
|-----------------|-------|------|----------|-----|
| Ammonium-ion    | 0.18  | 0.34 | 0.26     | 0.5 |
| Nitrate-anion   | 3.7   | 2.35 | 4.9      | 40  |
| Nitrite-anion   | 0.17  | 0.24 | 0.26     | 0.08|
| Sulfate-ion     | 257.1 | 210.7| 350.7    | 100 |
| Phosphate-ion   | 0.102 | 0.134| 0.68     | 0.05|
| Chloride-ion    | 122.8 | 130.7| 79.7     | 300 |
| Iron            | 0.18  | 0.35 | 0.21     | 0.1 |

The phytoremediation methods allowed to reduce the concentration of ammonium nitrogen, nitrites to values not exceeding the corresponding MPC, which amounted to 0.56, 0.07mg/l, respectively. The indicators for the content of pollutants in the effluent testify a complete purification of the content of ammonium nitrogen. During the studies, a slight excess in the content of iron, sulfates and chlorides in waste-water was noted. Macrophytes of the hydro-botanical facilities enrich the waste-water with oxygen, which contributes to the sedimentation of suspended solids. During the study, the indicator of the content of suspended solids decreased by 9.3 times. Reducing the concentration of chemical elements during waste-water can provide a high degree of post-treatment of industrial and domestic waste-water to the regulatory requirements for discharge into reservoirs, fishery-purposed ones. During the operation of the hydro-botanical facility, the content of ammonium nitrogen, iron decreased by 3 times, petroleum products, nitrates by 2 times, nitrites by 6.4 times, phosphates by 8.5
times. This dynamics confirms the studies carried out earlier. The process of reducing pollutants is due to the provision of higher absorption of non-organic forms of nitrogen and phosphorus by higher aquatic vegetation under the conditions of the already formed biocenosis of the hydrobiological facility. The indicator of the total microbial number provides an idea of the bacterial contamination of water, taking into account the microflora. As a rule, the total microbial number increases when storm water and domestic waste-water enter the post-treatment. A decrease in this indicator by 2 times shows the efficacy of the treatment technology and sanitary norms of waste-water discharged. The active growth of eichhornia during the growing season certainly contributed to more efficient absorption of nitrogen and phosphorus-containing compounds from waste-water, which significantly reduced the flow of nutrients into the waters of the water intake river.

| Table 3. Hydrochemical indicators of treated waste-water, 2016-2018 (mg/l) |
|--------------------------------------------------|
| Indicator (mg/l)  | 2016  | Study Time | 2017  | 2018  | MPC  |
| Ammonium-ion      | 1.94  | 0.6        | 0.56  | 0.5   | 0.5  |
| Nitrate-anion     | 81.78 | 51.01      | 38.06 | 40    | 40   |
| Nitrite-anion     | 0.45  | 0.1        | 0.07  | 0.08  | 0.08 |
| Sulfate-ion       | 164.25| 102.3      | 112.9 | 100   | 100  |
| Phosphate-ion     | 1.03  | 0.56       | 0.12  | 0.05  | 0.05 |
| Chloride-ion      | 312.36| 324.45     | 308.65| 300   | 300  |
| Iron              | 0.63  | 0.43       | 0.20  | 0.1   | 0.1  |
| Oil products      | 0.09  | 0.04       | 0.04  | 0.05  | 0.05 |
| Suspended matters | 158.27| 27.89      | 16.91 | 1.995 | 1.995|
| General mineralization (solid residue) | 1065   | 970        | 980   | 1000  | 1000 |

4. Conclusion
1. An assessment of the hydrochemical parameters of the natural waters of the water intake river indicates a slightly alkaline pH value, an increase in the concentration of suspended solids, solids, permanganate oxidation during spring high water period, which is denoted as average, which corresponds to the physical and geographical zonality, and the MPC exceeded the fishery in terms of nitrite, sulfate, nitrogen ammonium, phosphates, iron.

2. The excess of the maximum allowable concentrations of biochemical oxygen consumption was found to be by 1.1–2.5 times. The flow of nitrites with treated effluents into the river water ranged from 3.2 MPC to 2.1 MPC, sulfates 3.5 MPC, phosphates from 2 MPC to 13.6 MPC.

3. The phytoremediation methods allowed to reduce the concentration of ammonium nitrogen, nitrites to values not exceeding the corresponding MPC, which amounted to 0.56, 0.07mg/l, respectively. The phosphate content in the effluent decreased by 8.5 times, nitrite by 6.4 times, ammonium nitrogen, iron by 3 times, petroleum products, nitrates by 2 times. The active growth of eichhornia during the growing season has significantly reduced the flow of nutrients into the water of the river intake.

Acknowledgement
The author is grateful to the laboratory of sewage treatment facilities “Andropovskoye”, the branch of the state unitary enterprise “Stavropolkravodokanal” – “Yuzhny”, which provided the support in carrying out a set of analysis that allow monitoring the content of pollutants in waste-water at all stages of treatment.

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