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Bioremediation of Wastewater of Osh City of Kyrgyzstan with *Lemna minor* and *Azolla caroliniana*

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ABSTRACT

Under conditions of increased pollution of water resources, the search for effective and environmentally safe methods of wastewater treatment becomes an urgent task. As noted by many researchers *Lemna minor* L. and *Azolla caroliniana* have great potential for biological treatment of wastewater. The present study is devoted to the biological treatment of municipal wastewater of Osh city (Kyrgyzstan) using aquatic plants *Lemna minor* L. and *Azolla caroliniana* Willd. Experiments were conducted in concrete basins of treatment facilities. The area of each pool was 1 m^2, depth 30–45 cm. The temperature of nutrient media ranged from 20 to 35 °C, pH from 6.1 to 8.7, and light intensity from 284 to 360 W/m^2FAR. The results showed that the cultivation of *Lemna minor* resulted in the oxygenation of wastewater and, a significant reduction of pollutants and pathogens. At the same time, the use of *Azolla caroliniana* provided a significant improvement in the physicochemical characteristics of water - reduction of BOD_5 to 4.3 mgO_2/L, disappearance of all forms of nitrogen, as well as improvement of transparency and elimination of unpleasant odor. Thus, both plants showed high potential as biological

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treatment agents. The obtained data confirm the prospect of their application for a sustainable water treatment system in the conditions of southern regions of Kyrgyzstan.

Keywords: *Lemna minor* L.; *Azolla caroliniana* Willd; Cultivation; Biological Treatment; Wastewater; Osh Wastewater Treatment Plant

1. Introduction

SDG Target 6.3 is stated as follows: "By 2030, improve water quality by reducing pollution, eliminating waste discharges and minimizing releases of hazardous chemicals and materials, halving the share of untreated wastewater and significantly increasing recycling and safe reuse of wastewater worldwide" (https://www.un.org/sustainabledevelopment/ru/water-and-sanitation).

The current environmental situation and the state of environmental protection activities in some Central Asian countries requires not only accelerated development and adoption of effective measures for rational nature management and environmental protection but also the solution of urgent scientific problems, in particular, the development of appropriate water treatment biotechnologies.

Taking into account global trends in water supply and wastewater disposal, as well as the relevance of the problem of water pollution, biological methods of wastewater treatment are becoming more and more in demand. One of the most promising areas is the use of aquatic plants for biological wastewater treatment, which allows not only to reduce pollution of water bodies, but also to create environmentally safe and sustainable treatment systems. Plants such as *Lemna minor* L. and *Azolla caroliniana* Willd. Are actively studied as effective means for the biological treatment of water bodies due to their ability to absorb organic and inorganic pollutants, as well as to release oxygen that promotes microbiological oxidation of pollutants.

In Kyrgyzstan, including in its southern regions, water is a key resource but also faces a pollution problem. Many water bodies and rivers, including wastewater, contain large amounts of organic and inorganic pollutants, including nitrogenous compounds, phosphates, microorganisms, and other harmful substances. In this regard, the application of biological treatment methods using aquatic plants has a number of advantages, including environmental safety, low operating costs, and high efficiency.

The situation is especially urgent in cities such as Osh, where the rapidly growing population and increasing pollution of water resources require the development and implementation of new treatment technologies. The problem of wastewater pollution is not only environmental but also economic, as polluted water affects the health of the population, as well as the state of ecosystems.

Recent studies on biological wastewater treatment emphasize the importance of phytoremediation and biocatalytic technologies. Pranta et al. (2023) examine the issue of eutrophication in aquatic ecosystems, highlighting the need for effective wastewater management to prevent nutrient accumulation and the subsequent decline in water quality [1–4]. Tang (2024) explores advanced biocatalytic approaches for dye removal from wastewater, including the use of immobilized enzymes such as laccase and peroxidase, as well as microorganisms, demonstrating high efficiency in industrial wastewater treatment [5]. Meanwhile, Tang and Law (2019) investigate the phytoremediation potential of *Mucuna bracteata* in soil contaminated with crude oil, revealing its ability to degrade hydrocarbons and improve soil properties [6]. These studies underscore the promising role of integrating phytoremediation using aquatic plants such as *Lemna minor* and *Azolla caroliniana* into biological wastewater treatment systems, particularly in the context of sustainable water resource management in regions like Osh, Kyrgyzstan.

To accelerate wastewater treatment, a biological method of treatment is recommended by enriching phylogenesis with a green mass of microscopic algae and creating thickets of aquatic and wetland plants. The biological method of wastewater treatment removes about 80% of organic pollutants, the physical and chemical method - 40%, the mechanical method - about 30%. Thus, for example, in climatic conditions of the south of Kyrgyzstan during 6–8 months a year, it is possible to actively apply biological methods of treatment with the cultivation of various algae and higher aquatic plants and bring the degree of wastewater treatment to 90–99%.

It is known that aquatic plants play the role of biological filters, and contribute to the improvement of the oxygen regime in the water body. At the same time, they absorb mineral and organic components from polluted waters and release a lot of oxygen necessary for microbiological oxidation of organic substances. As a result, the water is purified and made suitable for reuse for various purposes such as irrigation, ecosystem restoration, and even, in some cases, for consumption.

However, the use of aquatic plants for wastewater treatment requires a detailed study of their effectiveness, especially under the conditions of climatic and environmental factors specific to Kyrgyzstan. Water bodies and vegetation of the Kyrgyz Republic are constantly affected by sharply continental arid climatic conditions. In recent years, there has been a noticeable increase in the pollution of water resources by wastewater from agricultural production and industrial enterprises, often without treatment facilities and located mainly near canals, collectors, floodplains of rivers, and other water bodies. The level of environmental pollution, despite the measures taken, is decreasing extremely slowly, and for some components remains threateningly high. Therefore, the study of effective methods of wastewater treatment using aquatic plants such as *Lemna minor* and *Azolla caroliniana* is an urgent and important step in solving the problem of improving the quality of water resources in the country.

The use of aquatic plants such as *Lemna minor* and *Azolla caroliniana* for the biological treatment of municipal wastewater is a promising and environmentally friendly approach. This method utilizes the natural phytoremediation capabilities of these plants to remove pollutants from wastewater.

The use of aquatic plants for wastewater treatment has gained popularity in recent decades. Plants are particularly sought after for their ability to absorb organic and inorganic pollutants, as well as release oxygen, which helps improve water quality. Biological treatment methods are at the forefront of modern water treatment technologies and are actively used around the world to reduce water pollution and improve water quality.

The potential economic benefits of using *Lemna minor* and *Azolla caroliniana* in wastewater treatment include the production of bioenergy and valuable by-products, as well as the possibility of reuse of treated wastewater in agriculture [7].

Lemna minor L. as one of the best known members of the family Lemnaceae, has been widely studied and applied for biological treatment of water bodies. According to studies, by Sun et al. (2020) and Jana et al. (2024), *Lemna minor* effectively purifies water from nitrogen, phosphorus, and organic matter, which makes it an important tool in water treatment [8, 9]. Walsh et al. (2024) also noted that this plant actively absorbs toxins and promotes their detoxification, making it valuable for the removal of pollutants from wastewater [10].

In addition, *Lemna minor* has the ability to biologically detoxify toxic substances such as heavy metals as well as petroleum products, making it suitable for the treatment of water contaminated with industrial wastes. This is emphasized by studies by Sufian et al. (2022) who also showed that *Lemna minor* has a high growth rate and the ability to absorb significant amounts of organic matter [11].

Azolla caroliniana Willd. - is another aquatic plant of the Azollaceae family that is used for water treatment due to its ability to absorb pollutants. Sufian et al (2022) in their work confirmed the effectiveness of Azolla in removing phosphate and organic matter from wastewater, which emphasizes its great potential in the treatment of polluted water bodies [11]. Rifai et al. (2024) and Deval et al. (2012) also showed that Azolla can be used to treat both wastewater and water contaminated with agricultural wastes, providing quality treatment of mineral pollutants and pathogens [12, 13].

Long-term studies by Kara (2004) and Amin Mojiri et al. (2021) showed that *Lemna minor* and *Azolla caroliniana* can effectively reduce the concentration of both organic and inorganic pollutants such as nitrate, nitrite, ammonia, and phosphate [14, 15]. These plants, with their high adsorption capacity, absorb minerals, heavy metals, nitrates, and other harmful substances into the water, significantly improving water quality. It is important to note that these plants are able to purify water not only from organic pollutants but also from bacterial infections, which is especially important for water supply and public health protection.

In addition, Sivakumar et al. (2015) in their study showed that *Lemna minor* and *Azolla caroliniana* can actively absorb carbon dioxide and release oxygen, helping to improve the oxygen balance of water bodies [16]. This makes these plants not only effective water purifiers, but also important players in maintaining the ecological balance in water bodies, especially under oxygen-deficient conditions.

Alvarado et al. (2008) investigated the possibility of using *Lemna minor* biomass as a feed additive and showed that it contains significant amounts of proteins, carbohydrates, vitamins, and minerals [17]. This holds promise not only for wastewater treatment but also for the utilization of aquatic vegetation as an environmentally friendly and nutritious resource for feed in agriculture. Ahmadi (2024) also noted that *Azolla caroliniana* has excellent nutritional properties, making it a good source of forage biomass that can be utilized in livestock and agriculture [18].

Other researchers such as Rofkar et al. (2014) and Deval et al. (2012) consider aquatic plants as an important component of water quality management [13, 19].

Aquatic plants such as *Lemna minor*, *Spirodela polyrrhiza*, and *Azolla caroliniana* can produce significant biomass that not only purifies water but also serves as an environmentally friendly and sustainable source of bioactive substances for agricultural production [20].

Studies have also shown that aquatic plants can effectively purify water from other pollutants such as chlorides, sulfates, and other ions, making them versatile agents for wastewater treatment. Daud et al. (2018) and Song et al. (2018) noted that plants such as *Colocasia esculenta*, *Pistia stratiotes*, *Eichhornia crassipes*, *Phragmites australis*, *Azolla filiculoides*, *Typha domingensis*, *Hydrilla verticillata* and others can also be used to treat water bodies and wastewater [21, 22].

Thus, numerous studies confirm the high potential of *Lemna minor* and *Azolla caroliniana* as effective agents for biological wastewater treatment. These plants not only help to improve water quality but also contribute to an environmentally friendly solution to the problem of water pollution [23].

As noted by Khan et al. (2020) *Lemna minor* has shown significant potential in treating heavy metals such as cadmium (Cd), lead (Pb), and nickel (Ni). It can transport and accumulate these metals, which makes it a suitable target for the treatment of heavy metal-contaminated wastewater [24, 25].

The aim of the study is to evaluate the effectiveness of aquatic plants *Lemna minor* and *Azolla caroliniana* for biological treatment of municipal wastewater in the city of Osh, taking into account regional climatic and environmental conditions.

2. Materials and Methods

For cultivation of aquatic plants *Lemna minor* L. and *Azolla caroliniana* Willd. We used wastewater from wastewater treatment plants in Osh City, pre-treated in aeration tanks. These waters are typical municipal wastewaters containing a variety of pollutants, including organic matter, nitrates, phosphates, and microorganisms that are complex mixtures, making them suitable for testing the efficiency of biological treatment.

The studies were conducted in specialized concreted basins located within the wastewater treatment plant. The area of each pool was 1 m² and the depth was 30–45 cm. These parameters were chosen to reflect typical conditions in wastewater treatment plants and optimal conditions for aquatic plant growth. The temperature of the nutrient media varied from 20 °C to 35 °C, which corresponds to the climatic conditions of the southern regions of Kyrgyzstan, where the water temperature in summer can fluctuate within such limits. The pH of the effluent water ranged from 6.1 to 8.7, which also reflects the natural conditions of water bodies in the region, and the light intensity ranged from 284 to 360 W/m² FAR, which corresponds to conditions in open water bodies in summer. The medium was renewed weekly, bringing it to the original concentration.

To stimulate aquatic plant growth and maximize treatment efficiency, the nutrient media were renewed weekly, maintaining the original concentration of components, while biomass growth was removed every three days to maintain optimal mother culture density.

1. The Winkler method (classical iodometric method) was used to measure BOD_5. The sample was incubated for 5 days at 20 °C, after which the amount of dissolved oxygen was measured before and after incubation.
2. Phenols were determined by extraction-photometric method after distillation with steam, which allows us to accurately measure the concentration of phenolic compounds that are toxic to aquatic organisms.
3. Photometric methods for the determination of nitrate, nitrite, and phosphate - these methods allow effective measurement of nitrate and nitrite, which are often present in wastewater as a result of fertilizer use in agriculture and emissions from industry. Phosphate determination was carried out using a photo colorimetric method, which

allows accurate determination of the level of phosphorus-containing substances that play a key role in the eutrophication processes of water bodies.

4. Dissolved oxygen (DO) content - was measured using oxygen sensors, which allowed us to accurately monitor changes in the oxygen regime of wastewater during the cultivation of aquatic plants.
5. Watercolor and visual assessment of water - watercolor of the wastewater was assessed visually using a scale, which allowed us to record changes in water clarity and saturation.
6. Suspended solids and dry residue analysis - suspended solids and dry residue were analyzed to assess the degree of water purification from solids and were determined using centrifugation and drying in a desiccator at 105 °C.

The cultivation of aquatic plants *Lemna minor* L. and *Azolla caroliniana* Willd. Was carried out under conditions as close as possible to natural conditions, taking into account all factors affecting their growth and productivity. *Lemna minor* L. and *Azolla caroliniana* Willd. Were cultivated in wastewater in order to utilize them as a biological agent for water treatment. The methodology used involves planting aquatic plants at a certain density in an area of 1 m² per basin. The biomass growth was monitored every 3 days to accurately assess the growth rate and changes in wastewater composition.

In addition, to evaluate the effect of the plant on water chemistry, experimental wastewater samples were analyzed at specific time intervals, which allowed dynamic monitoring of water quality changes during the treatment process.

Thus, all experiments were aimed at evaluating the removal efficiency of these pollutants using aquatic plants such as *Lemna minor* L. and *Azolla caroliniana* Willd. as well as analyzing changes in the physicochemical characteristics of water after exposure to the plants.

3. Results

To determine the treatment effect of *Lemna minor* L., we conducted a series of experiments on municipal wastewater from the city of Osh to assess the effect of *Lemna minor* on various pollutants in wastewater. During the experiment, we used different stages of wastewater treatment from wastewater treatment plants in the city, including outputs from mechanical treatment, sand traps, aeration tanks, and chlorinators. Laboratory-grown rye was introduced into the basins at a rate of 500 g of fresh biomass per 1 m². Water parameters such as temperature and pH were monitored and the chemical composition of the wastewater was analyzed.

Lemna minor reduces concentrations of total dissolved solids, salinity, and turbidity in wastewater, contributing to its overall purification (**Figures 1** and **2**).

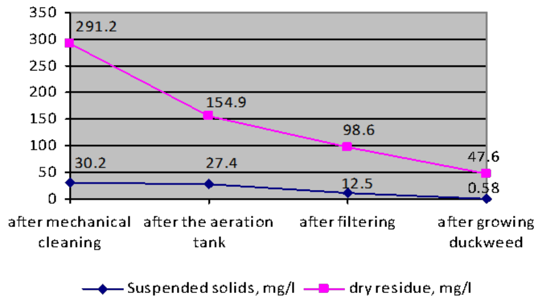

Figure 1. Changes in physical indications during the cultivation of *Lemna minor.*

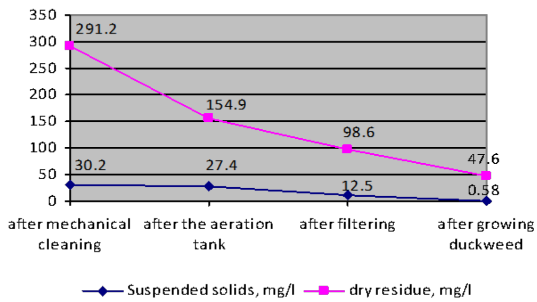

Figure 2. Changes in chemical readings during cultivation of *Lemna minor.*

The change in contaminant content after biological treatment is presented in **Table 1**.

Suspended substances. The highest suspended solids content was observed in the sample after mechanical treatment (sample No. 1), which amounted to 184 mg/L. In the process of wastewater treatment using cassava, a decrease in suspended solids content was observed. The lowest suspended solids content was observed in the sample after chlorinators (sample No. 4), which amounted to 39 mg/L. After the application of additional treatment with cassava, the suspended solids content decreased significantly to 0.68 mg/L.

Dry residue. The maximum dry residue content was also recorded in sample No. 1 (573 mg/L), which corresponds to a high level of contamination after mechanical treatment. After additional treatment with small cassava the content of dry residue decreased to 47.6 mg/L, which confirms the high efficiency of this treatment method.

Petroleum products. The content of petroleum products in wastewater was 0.7 mg/L in all samples. After pretreatment with small cassava, the content of petroleum products decreased to 0.5 mg/L. Although this effect is not as significant, cassock still shows its ability to purify water from petroleum products.

Phosphates. Phosphates, which are one of the important pollutants in water bodies, were found in the highest amount in sample No. 1 (4.6 mg/L). The pretreatment process using cassava reduced phosphate content to 0.12 mg/L, which is a significant improvement in wastewater quality.

Iron. The maximum iron content was recorded in the samples after mechanical treatment, sand traps, and aeration tanks (0.09 mg/L), while in the sample after chlorinators the iron level was much lower - 0.02 mg/L. After the application of cassava for wastewater pretreatment, the iron level remained unchanged at 0.02 mg/L, indicating the effectiveness of iron removal at the filtration stage.

Biochemical oxygen demand (BOD_5). The maximum value of BOD_5 was recorded in sample No. 1 (167.2 mg/L), which confirms the high content of organic pollutants in the wastewater at this stage of treatment. The BOD_5 content decreased to 13 mg/L in the sample after chlorinators. After pretreatment with small cassava, BOD_5 decreased to 3.85 mg/L, confirming a significant improvement in the organic component of the water.

Chlorides. The chloride content in sample No. 1 was 134.9 mg/L, and this content decreased to 109 mg/L after pretreatment with small cassava. This also indicates the moderate effectiveness of cassock in reducing chloride concentration in wastewater.

Nitrites. The highest nitrite content was recorded in sample No. 1 (0.8 mg/L). However, after pretreatment with cassava, the nitrite content decreased to 0.001 mg/L, showing a significant reduction in the concentration of nitrogenous pollutants.

Table 1. Wastewater treatment in Osh using *Lemna minor* L.

Parameters	Before Cultivation	After Cultivation
PH	6.2	7.6
Smell, score	4	without smell
Dissolved oxygen, mg O2/L	absent	18.4
BOD5 , mg O2 /L	173.2	3.8
Oxidability, mg O2 /L	79.8	3.9
Color	light pink	transparent
Ammonia mg/L	21.8	absent
Nitrite mg/L	0.4	absent
Nitrate mg/L	17.5	0.001
Suspended substances, mg/L	184	0.51
Dry residue, mg/L	283.6	41.3

Experimental results showed that the use of *Lemna minor* L. for the biological treatment of wastewater of Osh effectively reduces the concentration of various pollutants, including suspended solids, phosphates, iron, petroleum products, and nitrites. It was particularly effective in reducing organic pollutants such as BOD_5 and in phosphate treatment. Lemmican showed a significant improvement in water quality as evidenced by the reduced pollutant levels after its application.

The results also indicate the ability of *Lemna minor* L. to enrich water with oxygen, which improves conditions for microbiological purification and ecosystem restoration. Biological treatment using aquatic plants such as *Lemna minor* L. can be a promising method for wastewater treatment in the southern regions of Kyrgyzstan, such as Osh.

Azolla caroliniana is also effective in removing nitrogen, phosphorus, and potassium from wastewater, contributing to the detoxification process [25].

To determine the purifying effect of *Azolla caroliniana*, we also conducted experiments on the municipal wastewater of Osh City. The experiments were conducted in concrete pools on the territory of treatment facilities. The area of each pool was 1 m2, depth 10–15 cm. The temperature of nutrient media varied from 20 to 26 °C, pH - from 6.5 to 8.2, and light intensity - from 289 to 352 W/m2FAR. The nutrient medium was renewed weekly at the original concentration, and growth was removed every 3 days, leaving the original density of the mother culture.

The study showed that *Azolla caroliniana* can contribute to the removal of chlorine and total nitrogen from wastewater, emphasizing its potential in nutrient removal processes (**Table 2**).

After *Azolla caroliniana* cultivation, the physical properties and chemical composition of municipal wastewater improved. On the 8th day of the experiments, BOD_5 of municipal wastewater of Osh city decreased to 4.3 mgO_2 /L, dissolved oxygen content increased, all forms of nitrogen completely disappeared, water became transparent, and odorless.

During experiments using Azolla caroliniana, a significant reduction of nitrogen content in wastewater was observed. In particular, complete removal of ammonia and nitrite was observed, which is an important indicator of the efficiency of this plant in the wastewater treatment process.

Table 2. Treatment of municipal and domestic wastewater of Osh city with *Azolla caroliniana*.

Parameters	Before Cultivation	After Cultivation
PH	6.8	7.4
Smell, score	4	without smell
Dissolved oxygen, mg O2 /L	absent	4.8
BOD5 , mg O2 /L	150.6	4.3
Oxidability, mg O2 /L	79.1	29.6
Color	blackish-brown	transparent
Ammonia mg/L	5.23	absent
Chlorides mg/L	36.1	26.2
Suspended substances, mg/L	89.7	0.64
Dry residue, mg/L	109.2	69.3

Before the cultivation of Azolla caroliniana, the ammonia content in wastewater was 5.23 mg/L, but after application of the plant, ammonia was completely removed, indicating its ability to actively absorb and neutralize this toxic element. Also, the nitrite content in the water decreased from 0.4 mg/L to zero, emphasizing its ability to effectively remove nitrogenous pollutants.

These results confirm the potential of Azolla caroliniana as a biofilter for nitrogen removal from wastewater, which is important for preventing eutrophication of water bodies and restoring ecological balance in aquatic systems.

4. Discussion

During the experiments on wastewater treatment of Osh city using aquatic plants *Lemna minor* L. and *Azolla caroliniana* Willd. Interesting results were obtained, which allowed us to evaluate the effectiveness of these plants as a biological filter for the treatment of municipal wastewater.

Evaluation of treatment efficiency using *Lemna minor* L. In experiments using *Lemna minor* L., significant dynamics in the change of wastewater composition were established. During the study, wastewater from different stages of treatment (after mechanical treatment, sand traps, aeration tanks and chlorination plants) was subjected to additional biological treatment using cassava.

It is interesting to note that when *Lemna minor* L. was cultivated, the water significantly improved its physicochemical characteristics. Water transparency increased, and unpleasant odor disappeared, which also indicates a decrease in the content of volatile organic compounds and improved conditions for ecosystem restoration.

Thus, the use of *Lemna minor* L. for wastewater treatment not only effectively purifies water from organic and inorganic pollutants, but also contributes to ecosystem restoration and improves water quality for further use.

Evaluation of treatment efficiency using *Azolla caroliniana* Willd. *Azolla caroliniana* Willd. Also showed high efficiency in wastewater treatment. The experimental results demonstrated that this aquatic plant species could effectively treat wastewater from organic and inorganic pollutants. In particular, a significant decrease in biochemical oxygen demand (BOD_5) was observed on the 8th day of the experiments, which decreased from 150.6 mg/L to 4.3 mg/L.

The greatest treatment effect was observed in wastewater samples taken after primary mechanical treatment. This is explained by the fact that at this stage the waters still contain a significant amount of organic matter and pollutants that can be effectively removed by aquatic plants. As pollutants were removed during the wastewater treatment process, the effectiveness of *Lemna minor* L. application increased significantly. For example, the suspended solids content in the water before cultivation was 184 mg/L, while this decreased to 0.51 mg/L after cultivation with cassava. This indicates a high absorption of particulate matter by cassava, which serves as an excellent biofilter for organic pollutants.

The decrease in biochemical oxygen demand (BOD_5) is also an important indicator. In wastewater samples after *Lemna minor* L. cultivation, BOD_5 decreased from 173.2 mg/L to 3.8 mg/L, indicating a high level of water purification from organic matter that consumes oxygen during decomposition. This is a key indicator of reduced organic loading to water bodies and aquatic systems.

In addition, the dissolved oxygen level in water after *Azolla caroliniana* cultivation increased significantly to 4.8 mg/L, confirming the active role of the plant in improving the oxygen regime in wastewater. This indicator is critical for the restoration of water bodies, as oxygen is necessary to support the vitality of aquatic organisms and microorganisms.

Indicators such as ammonia and nitrite content decreased to zero values after *Azolla caroliniana* cultivation. This is especially important since ammonia and nitrite are toxic to aquatic ecosystems and can cause eutrophication of water bodies.

The aquatic plant *Azolla caroliniana* showed a high ability to absorb not only organic but also inorganic substances, which significantly improves water quality after filtration and contributes to the restoration of water bodies.

Comparative efficacy of *Lemna minor* L. and *Azolla caroliniana* Willd. Comparing the results obtained using *Lemna minor* L. and *Azolla caroliniana* Willd, it can be noted that both plants showed high levels of wastewater treatment, but their effectiveness on different pollutants differed slightly.

Lemna minor L. was more effective in removing suspended solids and organic pollutants. While *Azolla caroliniana* showed itself as a more active absorber of ammonia and nitrite, and also significantly improved the oxygen regime of water.

Both plants have a complex effect on water quality, which makes them effective for use in biological wastewater treatment at various stages of treatment, including treatment after mechanical and biological treatment.

Ecological and economic potential. Besides the obvious treatment efficiency, the use of *Lemna minor* L. and *Azolla caroliniana* Willd. In wastewater treatment has several additional benefits. First, the use of these aquatic plants helps to reduce pollution of water bodies without the use of chemical reagents, which makes the treatment process more environmentally friendly and safe. Secondly, both of these crops are highly productive and can be used to produce environmentally friendly biomass, which can be used as a feed additive for farm animals, as well as in biotechnological processes.

Plants used for wastewater treatment can become a source of environmentally friendly and nutritious biomass, which can be used in the feed industry or in production processes to create various products.

The results obtained confirm the high efficiency of using aquatic plants *Lemna minor* L. and *Azolla caroliniana* Willd. For municipal wastewater treatment. Both crops showed excellent results in reducing the level of organic and inorganic pollutants, improving the oxygen regime in water and eliminating unpleasant odors. In addition, they can be used to produce fodder biomass, which makes the wastewater treatment process economically feasible and environmentally friendly.

5. Conclusions

The conducted studies confirmed the high efficiency of using aquatic plants *Lemna minor* L. and *Azolla caroliniana* Willd. For biological treatment of municipal wastewater of Osh City. Both plants demonstrated the ability to significantly reduce concentrations of organic and inorganic pollutants, improve the oxygen regime of water and eliminate unpleasant odors.

Lemna minor L. was highly effective in removing suspended solids and organic pollutants, reducing BOD_5 from 173.2 mg/L to 3.8 mg/L and suspended solids from 184 mg/L to 0.51 mg/L. *Azolla caroliniana* Willd. Showed outstanding results in reducing ammonia and nitrite concentrations to zero and increasing dissolved oxygen levels to 4.8 mg/L, indicating its ability to improve the oxygen regime in water.

The use of these aquatic plants in the process of wastewater treatment not only effectively reduces the level of pollution, but also contributes to the restoration of ecosystems of water bodies. In addition, the obtained biomass can be used as a feed additive for farm animals or in biotechnological processes, which gives additional economic value to this treatment method.

Studies on the use of *Lemna minor* and *Azolla caroliniana* have identified several environmental and economic benefits that can contribute to the sustainable development of various industries.

Environmental benefits: carbon fixation, water filtration and improvement of water body quality, biodiversity and ecosystem support, and soil regeneration.

Economic benefits: use in agriculture as organic fertilizer, biofuel production, alternative protein source, reduced water treatment costs.

Overall, the use of *Lemna minor* and *Azolla caroliniana* in various sectors can not only reduce the ecological footprint of humans but also lead to economic benefits through the creation of new sources of raw materials, reduced product costs, and maintenance of ecosystem processes.

Thus, the use of *Lemna minor* L. and *Azolla caroliniana* Willd. Represents an environmentally safe, economically feasible, and effective method of biological wastewater treatment, which can be recommended for implementation at wastewater treatment plants of various settlements. The experimental results demonstrate their high efficiency in cleaning wastewater from organic and inorganic pollutants, improving water quality and environmental safety, which confirms their potential for application in large-scale urban wastewater treatment.

Author Contributions

All authors made significant contributions to this study as and Z.A. developed the study concept; I.G. and M.S. developed the methodology; M.K. and Z.B. contributed to data collection and resources; Z.A. supervised the data; G.M.k. prepared the initial draft, and O.K. and I.G. reviewed and edited the manuscript. B. K. supervised the study. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

All data supporting the reported results are provided within the manuscript. Additional data can be made available upon reasonable request.

Conflict of Interest

All the authors also declare that there is no conflict of interest in relation to the research, authorship, and publication of this study.

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