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Original Research Article

POLLUTANTS REMOVAL EFFICIENCY IN THE HYDROPONIC LAGOON OF THE WASTEWATER TREATMENT PLANT

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A b s t r a c t

Wastewater treatment in semi-natural systems, such as a hydroponic lagoon operating as the third stage of treatment, is becoming more and more popular because of the efficiency of organic matter and nutrient removal. The article presents an analysis of the efficiency of pollutant removal at the mechanical-biological wastewater treatment plant in Gronów with a capacity of Q_d = 1125m^3/day and a load of 9375 PE. The wastewater treatment plant operates on the basis of activated sludge and biomass settling technology on submerged flow beds. The treatment plant is characterized by a very high variability of wastewater inflow during the year due to periodic inflow of wastewater from tourist resorts in Łagów. The average efficiency of removing pollutants from wastewater was: BOD_5 - 98.5%, COD - 92.8%, total suspended solids - 93.2%, total nitrogen - 86.1% and total phosphorus - 69.5%. The study showed that the use of a hydroponic lagoon in the technological system improved the efficiency of wastewater treatment by 1.7% for BOD_5, 0.9% - COD, total suspended solids by 4.3%, 6.4% for total nitrogen and total phosphorus-3.3%.

Keywords: wastewater treatment, hydroponic lagoon, wastewater treatment plant

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1. INTRODUCTION

The composition of wastewater is one of the basic criteria for the selection and modernization of the sewage treatment technological system. It is diverse, variable over time and depends on many factors, including the nature and size of agglomeration and the share of industrial wastewater [1, 2]. Domestic wastewater contains about 60% of various types of organic substances dispersed in the water, and about 40% of inorganic substances, including human and animal excreta (urine and feces), food residues and waste, sand, soaps and other washing agents (detergents), and paper. The effectiveness of technological processes is mainly determined by the content of biodegradable substances.

In the technology of wastewater treatment, systems based on natural processes are now very important because of their efficiency in organic matter and nutrient removal [3]. Widespread eutrophication of surface water reservoirs as well as water courses and even coastal waters is a serious threat to natural ecosystems [4, 5, 6]. There is a strong need to reduce, among others, the amount of organic pollutants, because along with high concentration with phosphorus and nitrogen they play a main role in the process of water eutrophication. This is why wastewater extensive in these substances should be effectively treated in order to prevent water reservoirs from this negative phenomenon [7].

One of the methods based on natural processes is wastewater treatment in a hydroponic lagoon built in the shape of artificial river. Treatment processes that occur in this system are based on water self-treatment processes occurring in natural river ecosystems [8]. Biologically treated wastewater (after clarification in the secondary settling tank) flows through the hydroponic lagoon equipped with an aeration system. Preservation of constant flow, providing wastewater aeration in some chosen parts of the bed and light access enable to create appropriate conditions which are essential during self-treatment processes that are similar to the ones that occur in rivers environment [9, 10]. Macrophytes are planted on the surface of the wastewater. Their roots are immersed in the solution that provides nutrients for their growth [11, 12]. The root surfaces as well as the plastic panels used as a support for the growing plants are a very good environment for the growth of bacteria, protozoa, small invertebrates, algae and microalgae [13].

The aim of this study was to evaluate the efficiency of removing pollutants concentrations in municipal wastewater treated with the use of hydroponic technology as a tertiary treatment. Research was conducted to assess the suitability of hydroponic lagoon use for municipal wastewater treatment.

2. RESEARCH OBJECT

The wastewater treatment plant is located in the northwestern part of Gronów village (outside the residential area). Gronów is a village of about 100 inhabitants, located in the municipality of Lagów, Lubuskie province, Poland. The treatment plant receives domestic wastewater from seven villages: Gronów, Jemiołów, Łagów, Łagówek, Poźrzadło, Sieniawa and Żelechów. All of these villages, with the exception of Poźrzadło and part of Gronów (Stok), are fully sewered.

The wastewater treatment plant in Gronów was designed for a flow of Qd = 900 m^3/day and 9042 PE. Construction of the facility was completed in 2011. The treatment plant operates on the basis of activated sludge and settled biomass technology on submerged flow beds along with anaerobic sludge stabilization and periodic chemical phosphorus precipitation.

During 2018-2021, the average quarterly wastewater inflow to the treatment plant was in the range of 441 to 758 m^3/day (Fig. 1). The annual wastewater inflow to the treatment plant during the period under consideration was from 193,321 m^3 in 2020 to 210,491 m^3 in 2021.

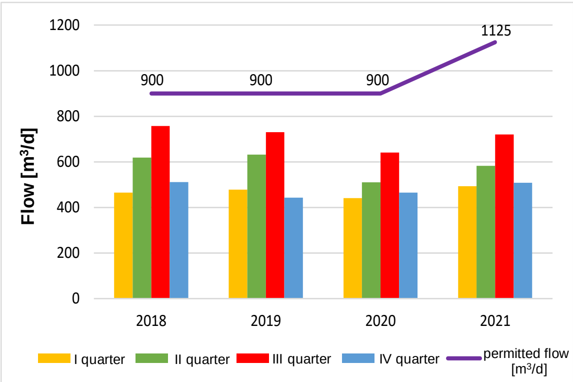

Fig. 1. Average quarterly wastewater flow in the wastewater treatment plant

Łagów municipality is a tourist municipality, 90 percent of its area is occupied by protected areas. The village of Łagów is located between two lakes - Trześniowskie and Łagowskie - where tourists from all over Poland come every summer. In Łagów alone there are 60 registered resorts, guesthouses, hotels and cottages. As a result, the sewage inflow to the treatment plant is characterized by very high variability throughout the year. In the summer season, the daily flow at the treatment plant is about 1100 m^3/d, in the off-season it averages 500-600 m^3/d, and in the winter months it is only 400 m^3/d.

Table 1 presents the loads of pollutants in raw wastewater in 2009-2019. The data presented here show a high irregularity of pollutant loads flowing into the treatment plant during the year.

Table 1. Average loads of pollutants flowing into the treatment plant in 2020-2021

Date	***Pollution load [kg/d]***		
	BOD_5	***COD***	***TSS***
04.2020	183	379	75
06.2020	159	438	192
09.2020	346	783	224
01.2021	220	346	162
03.2021	89	146	39
07.2021	185	412	182
09.2021	319	720	173
12.2021	107	226	77

According to the current water permit, the maximum average daily inflow is Qd = 1,125 m^3/day (9,375 PE), and the maximum annual Qd = 410,625 m^3/year. The previous water permit from 2011 (valid until July 2021) allowed a maximum average daily flow of Qd = 900 m^3/day and annual Qd = 328,500 m^3/year.

83.3% of wastewater flows into the treatment plant through municipal sewer systems, while the remaining 16.7% is sewage brought by slurry trucks from unsewered areas. In 2020, the Gronów wastewater treatment plant received 193,321.0 m^3 of wastewater, of which 32,239.3 m^3 were imported wastewater (about 17%).

Most of the municipality's development is residential buildings discharging domestic wastewater. The sources of industrial wastewater in the described area are car washes, gas stations and garages. The amount of wastewater they produce is small, accounting for less than 1% of the inflow.

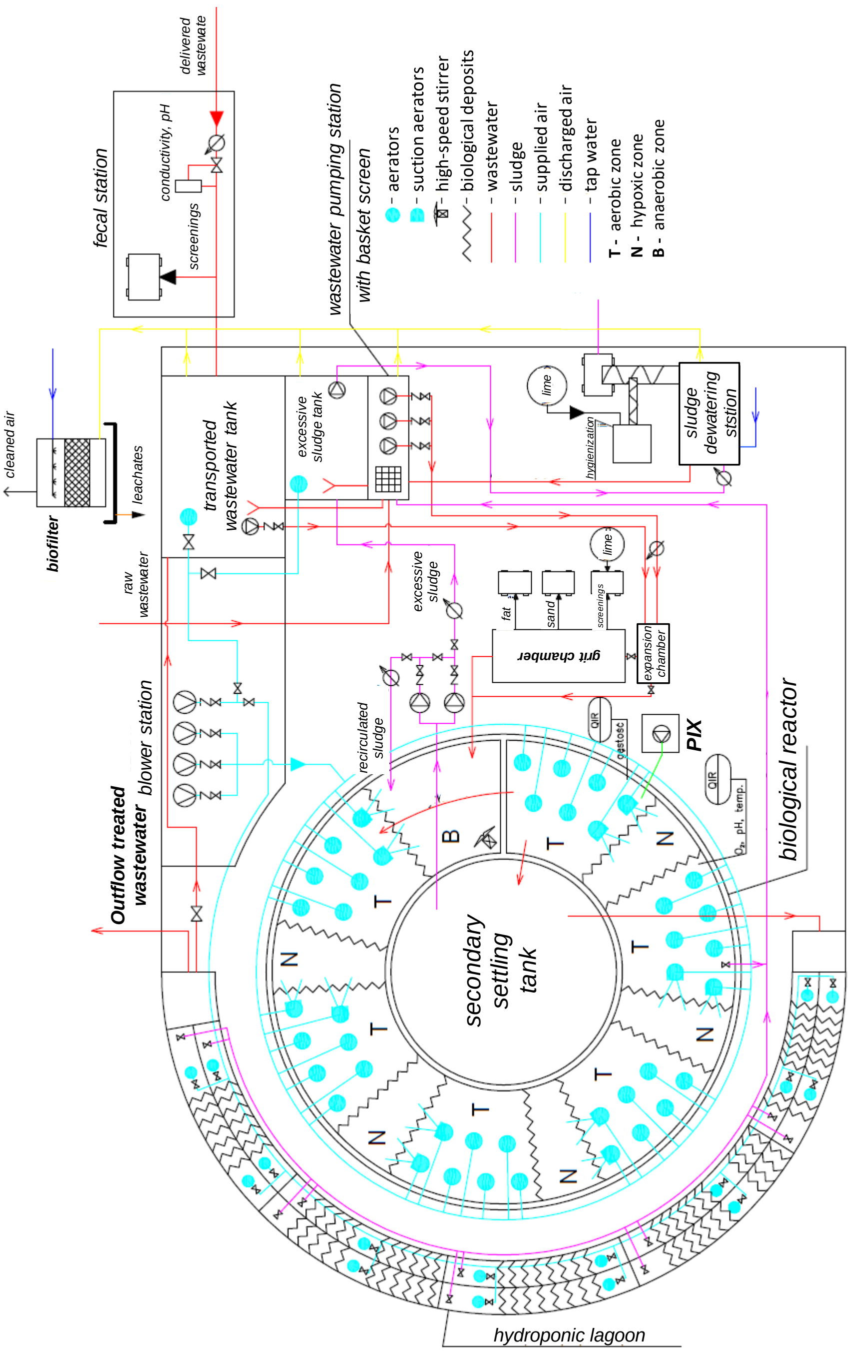

Fig. 2. Technological scheme of the wastewater treatment plant

The technological layout of the treatment plant is shown in Figure 2. Raw wastewater from the municipal sewerage system flows into a pumping station equipped with a basket screen with a clearance of 20mm. They then flow through a screen-sandblaster, where sand, suspended solids and grease are removed. The biological part of wastewater treatment is carried out in a biological reactor. It takes the form of a circulating activated sludge chamber, and its operation is based on the use of activated sludge in the form of flocculated suspended solids and biomass settled on submerged biological beds. The reactor is divided into 3 functional zones, separated by walls in the form of submerged biological beds:

– anaerobic zone, where the first stage of biological defosfation takes place (holding time: 1-1.5h),
– anoxic zone in which the denitrification process takes place (oxygen concentration: 0.2 ÷ 0.3 mg O_2/l; holding time about 20min),
– aerobic zone (with an oxygen concentration of - 2 mg O_2/l), where the second stage of biological defosfatation and nitrification takes place.

The amount of air supplied to the system depends on the oxygen demand, which is a function of the incoming load. Probes, installed in the reactor, measure the concentration of oxygen in the wastewater. Information on oxygen levels is transmitted to blowers, which supply air to the ASD aerators.

Wastewater flows through the reactor 3 to 6 times, with a holding time of 12 to 24 hours. At the end of the reactor, in the aerobic zone, where the wastewater flows into the secondary settling tank, PIX coagulant is periodically dosed for simultaneous precipitation of residual phosphorus not removed by biological defosfatation.

After biological treatment in the reactor, the wastewater flows into the secondary settling tank. It is a radial tank with horizontal flow and a diameter of Ø10m. It is located in the central part of the reactor. Sludge is scraped into the secondary settling tank funnel and then directed to the pumping station, where pumps separate it into recirculated sludge and surplus sludge. The wastewater is held in the settling tank for about 6h.

The final stage of biological wastewater treatment is a hydroponic lagoon in the form of a concrete tank 1.9m deep. This system works on the principle of a labyrinth created from flow-through biological deposits, which are a foundation for plant root assemblages and a habitat for epiphyton (periphyton) organisms. It simulates in an intensified way the self-purification processes taking place in rivers. Oxygen to the lagoon is supplied by ASD aerators, which are located in each section between the beds. The wall of the building is made of transparent cellular polycarbonate (Fig.3), so the plants have constant access to sunlight, this allows the lagoon to function all year round and protects it from external conditions.

Fig. 3. Hydroponic lagoon

3. RESULTS AND DISCUSSION

In accordance with the applicable water and legal permit the maximum concentrations of pollutants in the wastewater discharged to the receiver are respectively:

- BOD_5 – 25 mg O_2/l
- COD – 125 mg O_2/l
- TSS – 35 mg/l

The issued water-legal permit does not set permissible concentrations of total nitrogen and total phosphorus in the treated wastewater.

BOD_5 in raw wastewater was in the range of 181 ÷ 563 gO_2/m^3 (average: 388.3 gO_2/m^3). In treated wastewater, BOD_5 reached values of 1.6 to 8.3 gO_2/m^3 (average: 4.8 gO_2/m^3). The efficiency of BOD_5 removal from wastewater was within the range of 97.7÷99.7 % (Fig. 4).

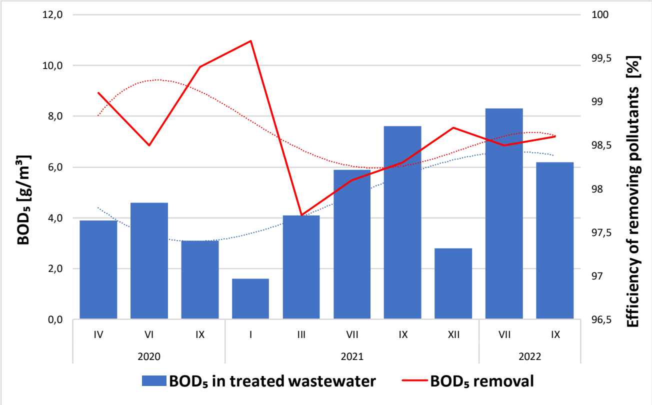

Fig. 4. BOD_5 in treated wastewater and removal efficiency

In order to evaluate the removal efficiency of pollutant indicators in the hydroponic lagoon in July and September 2022, the treated wastewater after the secondary settling tank was additionally tested.

In the wastewater before the hydroponic lagoon, BOD_5 values were reduced to 17.9 gO_2/m^3 (VII) and 13.6 gO_2/m^3 (IX). The efficiency of BOD_5 removal after the secondary settling tank was 96.8%. In the wastewater treated in the hydroponic lagoon, the BOD_5 values were respectively: 8.3 gO_2/m^3 in July and 6.2 gO_2/m^3 in September. The removal efficiency of the BOD_5 indicator - 98.5 and 98.6%. The average efficiency of BOD_5 removal from wastewater was 96.8% after the secondary settling tank and 98.5% after the hydroponic lagoon. The total efficiency of wastewater treatment increased by 1.7%.

The values of the COD index in raw wastewater, in the period 2020-2022 ranged from 296 to 1,224 gO_2/m^3. The average value of COD in raw wastewater was 772.4 gO_2/m^3. In treated wastewater COD reached values of 21 to 79 gO_2/m^3 (average: 53.7 gO_2/m^3). The efficiency of COD removal from wastewater was within the range of 85.1÷97.2 % (Fig. 5).

COD in wastewater samples taken after the secondary settling tank was 73 gO_2/m^3 in July and 55 gO_2/m^3 in September. At this stage of wastewater treatment, indicator removal efficiencies of 92.1% and 91.7% were achieved. The concentration of organic pollutants expressed as COD in wastewater collected downstream of the hydroponic lagoon was 66 gO_2/m^3 (VII) and 49 gO_2/m^3 (IX). The efficiency of COD removal from wastewater was, respectively: 92.9% i 92,6%. The average efficiency of COD removal from wastewater was 91.9% after the secondary settling tank and 92.8% after the hydroponic lagoon. The total efficiency of wastewater treatment increased by 0.9%.

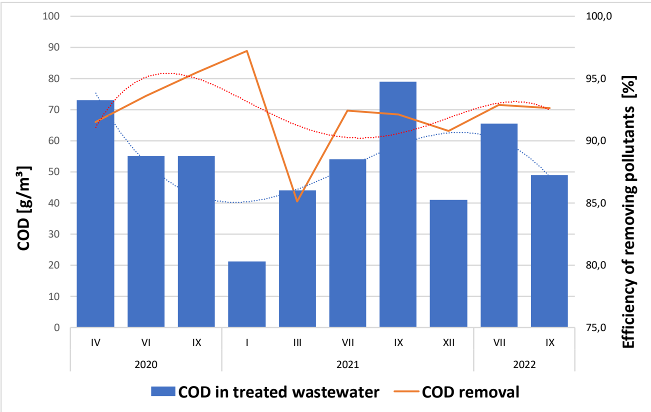

Fig. 5. COD in treated wastewater and removal efficiency

In the period 2020-2022 the concentration of total suspended solids in raw was in the range of 80÷376 g/m^3 (average: 253.6 g/m^3). The total suspended solids content in the wastewater treated was in the range of 2.0÷20.1 g/m^3 (average: 8.7 g/m^3). The effectiveness of the indicator removal from the wastewater was in the range of 91.9÷98.5 %. (Fig. 6).

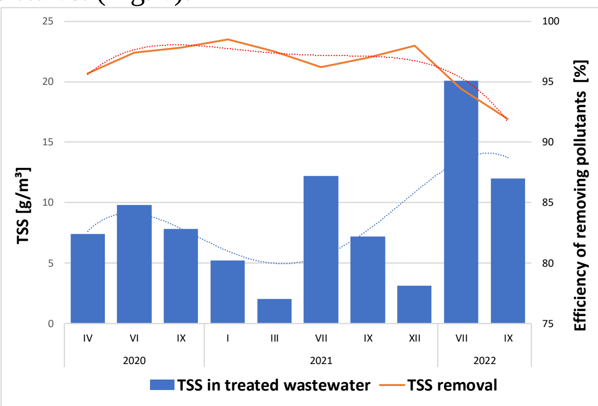

Fig. 6. Total suspension in treated wastewater and removal efficiency

The concentration of total suspended solids in wastewater collected downstream of the secondary settling tank was equal to 39.2 g/m^3 in July and 17.0 g/m^3 in September. The efficiency of total suspended solids removal calculated on this basis was 89.1% and 88.5%, respectively (average: 88.8%). At the end of the technological system, the amount of total suspended solids in the treated wastewater 20.1 g/m^3 in July and 12.0 g/m^3 in September. The efficiency of total suspended solids removal was 94.4% (VII) and 91.9% (IX), with an average of

93.2%. The use of a hydroponic lagoon in the technological system increased the removal efficiency of the indicator by 4.3%.

The concentration of total nitrogen in the raw wastewater was 79.93 gN/m^3 in samples taken in July and 33.6 gN/m^3 in September (Table 2). After the secondary settling tank, the amounts of nitrogen were reduced to 10.2 gN/m^3 (VII) and 9.4 gN/m^3 (IX). The removal efficiency of total nitrogen was respectively: 87.2% i 72.0%. In the treated wastewater after the hydroponic lagoon, the amount of total nitrogen was at 5.6 gN/m^3 (VII) and 7.0 gN/m^3 (IX). The final removal efficiency of total nitrogen in the treatment plant was 93.0% in July and 79.2% in September. The use of a hydroponic lagoon increased the average efficiency of total nitrogen removal from wastewater by 6.4%.

Table 2. Changes in the concentration of pollutants after the subsequent stages of treatment

Indicator	Unit	Raw wastewater		Wastewater after a biological reactor and secondary setting tank		Wastewater after a hydroponic lagoon	
		VII	IX	VII	IX	VII	IX
BOD_5	gO_2/dm^3	563	428	17.9	14	8.3	6.2
COD	gO_2/dm^3	927	660	73	55	66	49
total suspended solids	g/dm^3	360	148	39.2	17	20.1	12
total nitrogen	gN/dm^3	79.93	33.6	10.2	9.4	5.6	7
total phosphorus	gP/dm^3	9.98	4.48	2.62	1.85	2.19	1.75

The concentration of total phosphorus in raw wastewater samples was 9.98 in July and 4.48 gP/m^3 in September. After the secondary settling tank, the amounts of total phosphorus were reduced to 2.62 gP/m^3 (VII) and 1.85 gP/m^3 (IX). The removal efficiencies of total phosphorus in the wastewater after the biological reactor were, respectively: 73.7% and 58.7%. In lagoon-treated wastewater, total phosphorus concentrations were 2.19 gP/m^3 (VII) and 1.75 gP/m^3 (IX). Total phosphorus in treated wastewater samples taken in July was removed with an efficiency of 78.1%, and 60.9% in September. The hydroponic lagoon improved the final removal efficiency of total phosphorus by an average of 3.3%.

According to the water-legal permit, the concentration of total nitrogen and total phosphorus in the treated wastewater at the Gronów treatment plant is not normalized. According to the Regulation of the Minister of Maritime Economy and Inland Navigation of 12 July 2019 on substances particularly harmful to the aquatic environment and the conditions to be met when discharging sewage into waters or soil, as well as when discharging rainwater or meltwater into waters or into devices aquatic (Journal of Laws 2019, item 1311) [14], in a treatment plant serving 2000-9999 PE and lying in an agglomeration, the maximum amount of total nitrogen in the treated wastewater should not exceed 15 gN/m^3. Concentrations of total nitrogen in both the wastewater collected after the secondary settling tank and the wastewater treated in the hydroponic lagoon do not exceed this value. The maximum allowable concentration of total phosphorus in treated wastewater should not exceed 2 gP/m^3. In July, the concentration of total phosphorus in the wastewater after both the secondary settling tank and the hydroponic lagoon was higher than 2 gP/m^3.

4. CONCLUSION

The wastewater treatment plant in Gronów is characterized by a very high variability of wastewater inflow during the year due to the periodic inflow of wastewater from tourist resorts in Łagów. In the period from June to September, a higher volume of wastewater flows into the treatment plant. In September, higher concentrations of pollutants in raw wastewater are also observed, which may be due to a higher volume of wastewater brought in from non-drainage tanks that are emptied after the summer season.

The wastewater treatment plant was characterized by high efficiency in removing pollutants. The average efficiency of removing pollutants from wastewater was: BOD_5 - 98.5%, COD - 92.8%, total suspended solids - 93.2%, total nitrogen - 86.1% and total phosphorus - 69.5%.

The study showed that the use of a hydroponic lagoon in the technological system improved the efficiency of wastewater treatment by 1.7% for BOD_5, 0.9% - COD, total suspended solids by 4.3%, 6.4% for total nitrogen and total phosphorus- 3.3%.

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