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THE SMALL WASTEWATER TREATMENT PLANTS – HYDROBOTANICAL SYSTEMS IN ENVIRONMENTAL PROTECTION

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Abstract: The paper presents results of research concerning operating of five small wastewater treatment plants working in two different technologies: hydrobotanical wastewater treatment plant and constructed wetland. Each object was designed for the treatment of domestic sewage after preliminary mechanical treatment in a septic tank. Hydrobotanical wastewater treatment plants and one of constructed wetland beds were built for treating sewage produced in educational institutions and resort. In the article attention is paid to possibility of exceeding the maximum allowable concentration of pollutants for three main indicators of pollution: BOD_5, COD, and total suspension. The reduction of these indices is required by the Regulation of the Minister of Environment [14] for wastewater treatment plants with PE < 2000.

In addition, the paper presents the effects of wastewater treatment to reduce biogens. The best quality of outflow was reached by outflows from constructed wetland treatment plants. None of the observed objects fulfilled the requirements in terms of allowable concentrations for total suspension. The most effective were objects operating in technology of “constructed wetland”.

INTRODUCTION

The National Programme for Municipal Waste Water Treatment (KPOŚK) is one of the legal acts regulating sewage management within Polish communes [6]. In accordance with the accession agreement, the national authorities assume responsibility of abating pollutant load discharged into environment along with waste effluents. In accordance with the dates presented in the National Program for Municipal Waste Water Treatment, individual agglomerations should be equipped with a central sewerage and a collective sewage treatment plant. It is a well-known fact that the communes will have problems with meeting deadlines for the construction of sewage treatment plants. Failure to meet the deadline involves an increase of fees for sewage discharge into environment [16].

The areas without a central sewerage are chiefly rural areas which have not been entered into the agglomeration limits. In accordance with the National Program for

Municipal Waste Water Treatment, the problem of sewage utilisation over such areas ought to be solved individually. A growing awareness of inhabitants of such areas brings about a growth in interest in household and local sewage treatment plants. The employment of the most straightforward variant of sewage treatment, which is based on a multi-chamber septic tank, is not sufficient any more. Increasingly, the more effective utilisation solutions of small amounts of sewage are being searched. In the case of small sewage treatment plants, irrespective of a type of a receiving body (surface running water or ground), the Ordinance of the Minister of Environment [14] determines required allowable concentration of the three basic pollution indicators BOD_5, COD and total suspended solids (TSS). In majority of cases, the reduction required by the Ordinance has already been achieved in so-called septic tanks.

Reduction of the concentration of biogenic compounds within sewage discharged into the environment is not legally required for sewage treatment plant < 2000 RLM [14]. Due to a growing number of new objects installed in different locations (e.g. terrain of valuable landscape), technologies assuring high reduction efficiency of nitrogen and phosphorus compounds [15, 19] ought to be employed.

Increasingly, hydrobotanical sewage treatment plants have become more popular forms installed in rural areas without central sewage [13, 17]. The solutions based on employment of environment, which is close to the natural one, are installed for single buildings and their clusters. Employment of that type of solutions is independent of soil environment. Sewage purification takes place in a specially prepared filling [5, 9]. In majority of cases, the purification process is closed in special containers which causes that location of such sewage treatment plant is independent of a depth of lying groundwater table and type of soil. Furthermore, in the case of hydroponic sewage treatment plants, the surface occupied by the object is small [9, 10].

Sewage purification in co-operation with ground and plant environment is a relatively new technology. The first hydrophyte solutions were applied broadly over 40 years ago. The general functioning principles of such objects consist in taking up of effluents by microorganisms which generate a bacterial jelly of effluents. Next, the effluents are released along with sewage into special bed [11]. Formulation of existing hydroponic systems was the result of a long-standing research work on root beds. As a result, a hydroponic object often described as “living machines” came into existence [8].

The hydroponic sewage treatment plants were employed in Europe until 1987 [2]. A sewage treatment plant called Biopax in Paczków is one of the first of such major solutions in Poland.

In the paper, the three objects working in hydroponic technology and two beds created as “constructed wetland” are compared with reference to the effects of purification and maximum allowable pollutant concentration determined in the Ordinance of the Minister of Environment [14].

MATERIALS AND METHODS

The research was conducted in three objects intended for a year-long purification of residential sewage generated in educational institutions located within Lower Silesia in localities such as Płoski, Ślubów, Irządze and in two objects working as “constructed wetland”. The sewage purified in hydroponic sewage treatment plants was discharged into surface waters feeding river basins of the River Barycz. The construction site of a sewage treatment plant was dictated by an additional educational utilization of the objects. The realisation of the objects was executed owing to the project entitled “Biodiversity Protection and Conservation of the Barycz Valley” conducted by "pro Natura", the Polish Society of Wildlife Friends in co-operation with the Lower Silesian Foundation for Eco-Development. The resources to finance the project came from the Global Environmental Facility GEF.

The sewage treatment plants employed to purify domestic wastewater operate in hydroponic system technology. They are constructed as concentric circular trenches with the depth and diameter 2.0 m. The plastic profiles with addition of LECA were used to fill the bed. On such fulfillment macrophytes were planted. The sewage movement in the ditches is forced by sewage pumps. The technology employed allowed to avoid common problems appearing in such types of sewage treatment plants, among other things, clogging up and a low resistance to frost. Furthermore, a merit of such type of solutions is a small surface required, which enables to localise the objects on small plots (Fig. 1).

Fig. 1a. Location of research objects

Fig. 1b. Object 1 in Paszków

Fig. 1c. Object 2 in Płoski

Fig. 1d. Object 3 in Ślubów

Fig. 1e. Object 4 in Irządze

Fig. 1f. Object 5 in Mroczen

According to Polish legislation, objects of such type ought to meet concentration levels required for three basic pollution indicators, that is, BOD_5, COD_{Cr} and total suspended solids when surface running water or ground is a receiving body of sewage [14].

The research conducted in sewage treatment plants aimed at determining changes within concentration of purified effluent run-off for selected pollution indicators as well as determining the effectiveness of treatment for eutrophic indicators such as total nitrogen and phosphorus.

After a preliminary mechanical purification in the septic tank, effluent samples and samples of purified effluent were taken on average once a month in the period from March 2010 – March 2011.

The analyses of effluent composition were carried out in accordance with binding norms. Efficiency of purification of the analysed pollution indicators was labeled and was compared with maximum allowable pollutant concentration determined in Polish legislation.

The "constructed wetland" beds, which were located in Paszków and Mroczeń, purified domestic wastewater coming from an adjoining holiday resort and a primary school. The ground and plant beds, which were planted with reeds, worked in a mixed system. A biological part of the sewage treatment plant in Mroczeń was designed as a two-part piston-powered bed (planted with willows and reeds) [12]. In both cases, after a mechanical purification the effluents were discharged into adjoining streams. After a mechanical purification and on the run-off the effluent samples were taken in the period from December 2009 – December 2010 (Paszków) and from January 2003 – January 2005 (Mroczeń). A characterisation of basic parameters is shown in Table 1.

RESULTS AND DISCUSION

The research of effluent composition inflowing into the object sewage treatment plants (Table 2) revealed that the concentrations of examined indicators were included within a very wide scope, and the average values for those indicators, which came from the whole research period, considerably diverged from each other.

Table 1. Summary of basic parameters of monitored wastewater treatment plants

Object*	Parameters					
	Capacity m^3/d	Surface m^2	Inhabitants	Fulfil	Hydraulic loading m^3/m^2d	Plants
No. 1	2,3	16,0	-	3 reactors	0,143	water iris *(Iris pseudacorus)*, siberian iris *(Iris sibirica)*
No. 2	3,0	16,0	177	4 reactors	0,186	
No. 3	4,3	30,0	197	6 reactors	0,143	
No. 4	4,0	214,1	22	4 beds	0,0187	reed *(Phragmites L.)*
No. 5	7,2	3 000	350	2 beds	0,0024	willow (Salix L), reed *(Phragmites L.)*

* objects in 1 – Płoski (hydroponic object), 2 – Ślubów (hydroponic object), 3 – Irządze (hydroponic object), 4 – Paszkowie (reed bed), 5 – Mroczeniu (reed bed)

When analysing the research results of effluent composition running off from septic tanks in the context of requirements imposed on purified effluents [14], one may state that in the case of pollutant concentration above the average value, they do not fulfill the requirements imposed on purified effluents. This indicates that domestic wastewater running off from pre-sedimentation (septic) tanks ought to be pretreated biologically.

The effluents of the highest pollutant concentration flowed into the object 5 (Table 2). The effluents of the lowest pollutant concentration were purified in the object 2. High pollutant concentration of effluents, which are subject to purification, may cause reduction of work efficiency of the objects in winter.

In accordance with the Ordinance of the Minister of Environment [14], small sewage treatment plants on the run-off are obliged to meet the requirements regarding the maximum allowable concentration for the three parameters (BOD_5, COD and total suspended solids). Considerably lenient requirements, which are posed on household sewage treatment plants, bring about a growing popularity of such household sewage treatment plants. Both the hydrobotanical and *constructed wetland* objects are more often constructed within terrain of valuable landscape due to their aesthetics and simplicity to incorporate into the surrounding landscape. Therefore, on account of environmental protection and a possible receiving body, more attention ought to be paid to reduction of biogenic substances in small treatment plants. An average physicochemical composition of effluents running off from the observed objects is presented in Table 3. The effluents, which were discharged into the receiving body installed in the object 3, were distinguished by higher concentration values of BOD_5, COD_{Cr}, total suspended solids and Total Nitrogen. This was the result of a too short storage of effluents in the tank. In the case of technology employed in the sewage treatment plant no. 3 the pump, which fed effluents into bed, worked at short breaks and pumped the inaccurately purified effluents.

The lowest values of the basic pollution indicators were obtained in the sewage treatment plant no. 4. The employment of a constructed wetland technology and the increase in active bed surface, which took part in purification, was reflected in lower

Table 2. Physico-chemical characteristic of outflow (after septic tanks) to wastewater treatment plants

The characteristic values	Parameters				
	BOD_5 mgO_2dm^{-3}	COD_{Cr} mgO_2dm^{-3}	Total suspension mg dm^{-3}	Total nitrogen $mgNdm^{-3}$	Total phosphorus $mgPdm^{-3}$
Object no. 1					
average	201,7	270,8	291,0	86,3	8,2
minimum	20,0	147,0	44,0	30,0	3,5
maximum	420,0	388,0	748,0	150,0	22,0
number of samples	N=9	N=9	N=9	N=9	N=9
Object no. 2					
average	95,0	141,3	154,0	42,4	4,9
minimum	20,0	39,0	32,0	15,0	0,8
maximum	200,0	457,0	468,0	75,0	12,0
number of samples	N=9	N=9	N=9	N=9	N=9
Object no. 3 for technical reason there was no possibility of collection of wastewater for research					
Object no. 4					
average	114,2	499,8	302,5	50,1	7,4
minimum	20,0	46,0	36,0	18,0	1,1
maximum	460,0	1500,0	720,0	106,0	18,7
number of samples	N=13	N=13	N=13	N=13	N=13
Object no. 5					
average	375,6	895,4	488,2	195,8	19,7
minimum	150,0	310,0	390,0	79,0	7,95
maximum	560,0	1666,0	760,0	312,0	31,8
number of samples	N=25	N=25	N=11	N=25	N=25

* objects in 1 – Płoski (hydroponic object), 2 – Ślubowie (hydroponic object), 3 – Irządzach (hydroponic object), 4 – Paszkowie (reed bed), 5 – Mroczeniu (reed bed)

concentration of biogenic substances observed on the run-off from the object no. 5. An average pollutant concentration on the run-off from the sewage treatment plant and maximum allowable concentration for both the oxygen and the biogenic indicators in the event when the purified effluents would be discharged into stagnant waters are shown in Figure 2.

According to average value of COD, for each analyzed objects it can be noticed that limited concentrations of COD presented in the Ordinance did not exceed the limits. However, for the entire research period, in the monitored COD values only object no. 1 (hydrobotanical) and no. 4 (reed-bed) showed no limits exceeding. Sewage treatment plants operating in natural environment are mainly used to reduce pollutions expressed by

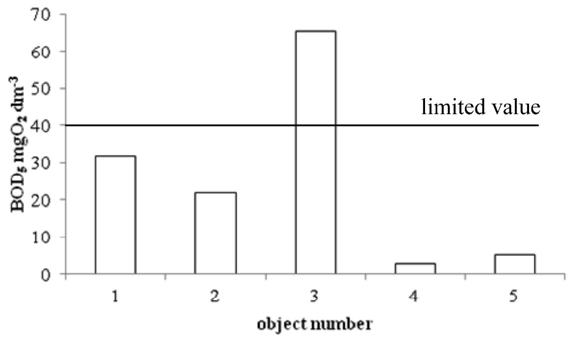
Table 3. Physico-chemical characteristic of treated wastewater outflow from wastewater treatment plants

The characteristic values	Parameter				
	BOD_5 mgO_2dm^{-3}	COD_{Cr} mgO_2dm^{-3}	Total suspension mg dm^{-3}	Total nitrogen $mgNdm^{-3}$	Total phosphorus $mgPdm^{-3}$
Object no. 1					
average	31,7	94,7	372,9	54,8	6,6
minimum	10,0	50,0	20,0	22,0	2,8
maximum	95,0	145,0	948,0	102,0	17,8
number of samples	N=9	N=9	N=9	N=9	N=9
Object no. 2					
average	21,8	107,3	121,3	50,4	5,1
minimum	10,0	52,0	10,0	9,0	2,6
maximum	40,0	191,0	328,0	95,0	12,5
number of samples	N=9	N=9	N=9	N=9	N=9
Object no. 4					
average	2,6	69,5	101,8	20,6	3,2
minimum	0,1	31,0	4,0	5,0	1,1
maximum	14,0	113,0	396,0	30,0	7,6
number of samples	N=13	N=13	N=13	N=13	N=13
Object no. 5					
average	5,2	86,0	338,9	0,3	0,42
minimum	0,5	18,4	180,0	18,0	0,02
maximum	20,0	174,0	560,0	5,5	1,8
number of samples	N=25	N=25	N=11	N=25	N=25

* objects in 1 – Płoski (hydroponic object), 2 – Ślubowie (hydroponic object), 3 – Irządzach (hydroponic object), 4 – Paszkowie (reed bed), 5 – Mroczeniu (reed bed)

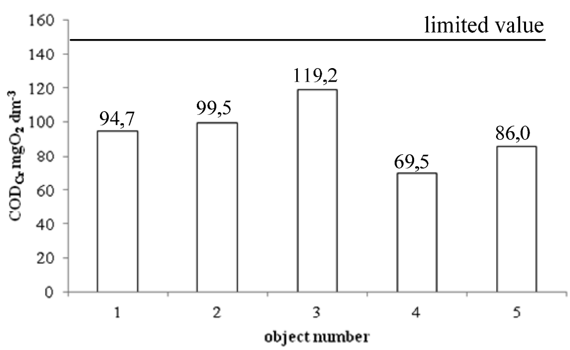
oxygen indices [17]. For two hydrobotanical objects limited BOD5 values were exceeded (Fig. 2).

The problem for both types of sewage treatment plants is to reduce the suspensions. Exceeding of suspension limits was recorded in more than 50% of the analyzed samples. The highest percentage was characteristic of outflows from sewage treatment plant in Mroczen. In the case of the constructed wetland sewage treatment plant, this might have been caused by a sewage treatment plant overloading (object no. 5) or a long-lasting (a twenty-year old) operation (object no. 4). In the case of hydroponic objects, the location of the sewage treatment plant in the vicinity of trees might have contributed to a secondary pollution of the run-off. Much less effective were removed biogens from hydrobotanical objects in relation to reed-bed sewage treatment plants. For each of these objects exceeding of limited total nitrogen concentrations was observed. Only the object



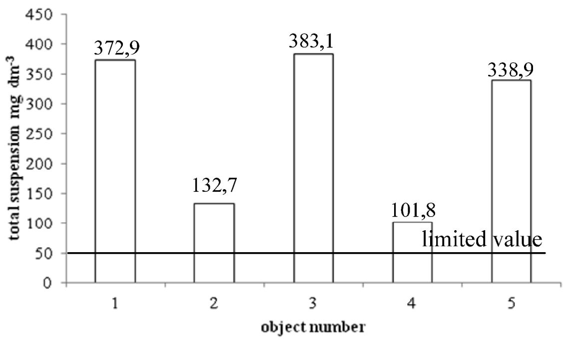
Nr obiektu	1	2	3	4	5
max. g/m^3	95,0	40,0	170,0	14,0	20,0
min. g/m^3	10,0	10,0	10,0	0,5	0,5
Number of exceeding	3	0	5	0	0
Permitted number of exceeding	2	2	2	2	2

Fig. 2a. The average composition of treated sewage outflowing from wastewater treatment plants (BOD_5) and limit values 1 – Płoski (hydroponic object), 2 – Ślubów (hydroponic object), 3 – Irządze (hydroponic object), 4 – Paszków (reed bed), 5 – Mroczeń (reed bed).



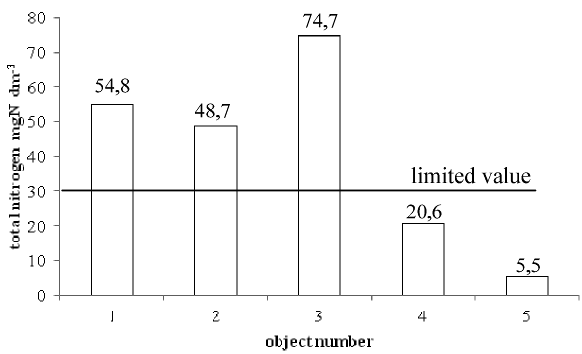
Nr obiektu	1	2	3	4	5
max. g/m^3	145,0	191,0	339,0	113,0	174,0
min. g/m^3	50,0	52,0	39,0	31,0	18,4
Number of exceeding	0	2	3	0	2
Permitted number of exceeding	2	2	2	2	2

Fig. 2b. The average composition of treated sewage outflowing from wastewater treatment plants (COD) and limit values, 1 – Płoski, 2 – Ślubów, 3 – Irządze, 4 – Paszków, M – Mroczeń



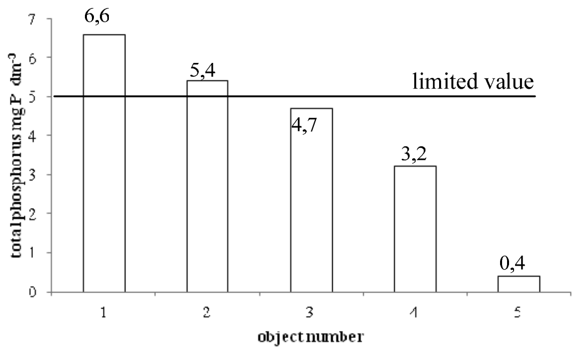
Nr obiektu	1	2	3	4	5
max. g/m^3	948,0	328,0	1600,0	396,0	560,
min. g/m^3	20,0	10,0	16,0	4,0	180,0
Number of exceeding	5	5	7	9	9
Permitted number of exceeding	2	2	2	2	2

Fig. 2c. The average composition of treated sewage outflowing from wastewater treatment plants (Total suspension) and limit values, 1 – Płoski, 2 – Ślubów, 3 – Irządze, 4 – Paszków, M – Mroczeń



Nr obiektu	1	2	3	4	5
max. g/m^3	102,0	95,0	190,0	30,0	15,2
min. g/m^3	22,0	9,0	22,0	5,0	0,3
Number of exceeding	6	7	7	0	0
Permitted number of exceeding	2	2	2	2	2

Fig. 2d. The average composition of treated sewage outflowing from wastewater treatment plants (total nitrogen) and limit values, 1 – Płoski, 2 – Ślubów, 3 – Irządze, 4 – Paszków, M – Mroczeń



Nr obiektu	1	2	3	4	5
max. g/m^3	17,0	12,5	9,5	7,6	1,8
min. g/m^3	2,8	2,5	2,3	1,1	0,02
Number of exceeding	4	2	3	2	0
Permitted number of exceeding	2	2	2	2	2

Fig. 2e. The average composition of treated sewage outflowing from wastewater treatment plants (total phosphorus) and limit values, 1 – Płoski, 2 – Ślubów, 3 – Irządze, 4 – Paszków, M – Mroczeń

operating in technology of "constructed wetland" were characterized by outflows with concentration of total nitrogen less than 30 g m^{-3} for entire research period. A similar trend (meeting the limited values) was observed for total phosphorus. The average value of this index, in both cases of constructed wetland's technology was not higher than characterized in the Ordinance. Constructed wetland in Mroczen (the only one of the monitored) recorded no exceeds of total phosphorus in the effluent.

An average sewage treatment plant performance was determined when comparing the parameters of effluents inflowing into the sewage treatment plant and the ones released into the receiving body

For the hydrobiological objects, an decrease of BOD$_5$ efficiency was observed in January (objects in Płoski and Ślubów) and in the spring and summer season (Płoski).

Sewage treatment plants with reeds planting, were characterized by small ranges of BOD5 reduction. The lower results of objects operating were noticed in the spring months (March, April for the both constructed wetlands) and in the summer (object in Mroczen). Hydrobotanical sewage treatment plants showed no seasonal dependence for treatment efficiency for COD. The object in Ślubów achieved the highest decrease of effectiveness in June–October, than in January, while for the object in Płoski the low reduction was observed only in March. Both treatment plants operating in the technology of "constructed wetland" responded by decrease of the effectiveness of work in January. Regardless of the technology, reduction of suspension was the most important problem for each of the sewage treatment plants. There was no trend in the effective operation for suspension reduction. The lowest reduction levels were observed in the spring and summer period as well as in the winter. The average reduction levels for suspension

Table 4. Average efficiency of wastewater treatment for selected indicators of pollutions

Object	Average efficiency in research period [%]														
	BOD_5			COD_{Cr}			Total suspension			Total nitrogen			Total phosphorus		
	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.
No. 1	42,4	76,6	97,6	18,5	62,5	82,9	-151,4	60,9	77,7	0,0	28,7	85,3	-36,3	12,9	71,4
No. 2	-50,0	53,5	94,0	-41,1	9,0	68,4	-262,5	21,4	80,0	-200,0	-26,7	73,5	-225,0	-0,12	58,2
No. 3	For technical reason there was no possibility of sampling sewage														
No. 4	83,3	96,6	99,9	-38,8	55,9	97,9	-31,1	59,7	98,1	-66,6	36,4	86,7	0,0	46,2	69,3
No. 5	94,6	98,8	100,0	63,4	90,6	100,0	-21,4	43,9	100,0	88,5	97,6	100,0	93,5	98,5	100,0

* objects in 1 – Płoskach (hydroponic object), 2 – Ślubowie (hydroponic object), 3 – Irządzach (hydroponic object), 4 – Paszkowie (reed bed), 5 – Mroczeniu (reed bed)

were in the range 21,4–60,9% and were lower than those achieved for the same index in similar objects [7, 20, 21]. The higher results compared to those obtained, were also observed for BOD_5 and COD in similar objects in Poland as well as in the world [1, 3, 4, 18]. For each sewage treatment plants total nitrogen and phosphorus were removed with the lowest treatment efficiency in the spring month (March and April). In the following months, a steady increase of treatment efficiency was observed, until the next reduction in October. Hydroponic technologies (objects no. 1 and 2), during the research period, were characterized by varying levels of pollutions reduction (Table 4). For object no. 2 there was also observed an outflow with higher concentrations of total nitrogen and phosphorus than in the inflow. The results of nutrient reduction were different than the effects of reduction for this index in similar objects [4, 11, 22, 23]. Such low levels of nutrients reduction for hydroponic sewage treatment plants could also be result of long breaks in pumps work supplying wastewater to the beds. The constructed wetland was characterized by higher treatment efficiency for biogens. The highest reduction effects were observed for object no. 5 in Mroczen. Taking into consideration the number of allowable exceeds of pollutants in treated sewage in relation to the number of samples that cannot fulfill the Ordinance, the objects no. 1 and no. 3 (hydroponic systems) do not fulfill the Ordinance for BOD_5, no. 3 for COD_{Cr}, and all analyzed objects for suspension. If the treated sewage were discharged to the stagnant water, the objects in Płoski, Ślubów, Irządze would not fulfill the Ordinance for total phosphorus and total nitrogen.

CONCLUSIONS

Based on the research conducted, the following conclusions were formulated:

1. The observed hydroponic objects and constructed wetlands treated in the normal operation did not fulfill the requirements according to [14].
2. The lowest treatment efficiency was observed in objects operating as hydroponic systems. Regardless of the location of sewage treatment plant the exceeding of limited values of BOD_5 and COD was noticed.
3. If the receiver of treated wastewater were stagnant water (lakes and inflows) the constructed wetland would not fulfill requirements for total nitrogen and total phosphorus.
4. The results of studies concerning sewage treatment efficiency for five analyzed hydroponic objects and constructed wetland operating in normal condition differ from those reported in the literature. Generally, the treatment efficiency for oxygen indexes and for total nitrogen and phosphorus was lower than that reported in the literature.

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MAŁE OCZYSZCZALNIE ŚCIEKÓW – SYSTEMY HYDROBOTANICZNE W OCHRONIE ŚRODOWISKA

W pracy przedstawiono wyniki badań dotyczące pracy małych pięciu oczyszczalni ścieków pracujących w dwóch technologiach: oczyszczalnie hydrobotaniczne oraz constructed wetland. Każdy z obiektów przeznaczony był do oczyszczania ścieków bytowych po wstępnym mechanicznym oczyszczaniu w osadniku gnilnym. Oczyszczalnie hydrobotaniczne oraz jeden z obiektów constructed wetland wybudowano w celu oczyszczania ścieków pochodzących z placówek oświatowych, pozostałe złoże gruntowo-trzcinowe oczyszczało ścieki z ośrodka wypoczynkowego. W artykule zwrócono szczególną uwagę na możliwość przekroczenia maksymalnego dopuszczalnego stężenia zanieczyszczeń wg obowiązujących w Polsce przepisów, dla trzech podstawowych wskaźników zanieczyszczeń: BZT_5, ChZT oraz zawiesiny ogólnej. Redukcja tych indeksów wymagana jest Rozporządzeniem MŚ [14] dla oczyszczalni o RLM < 2000. Ponadto w pracy przedstawiono również efekty oczyszczania na rzecz redukcji biogenów. Najlepszą jakością charakteryzowały się odpływy z oczyszczalni pracujących w technologii constructed wetland. Natomiast żaden z obserwowanych obiektów nie spełniał wymogów pod względem dopuszczalnych stężeń dla zawiesiny ogólnej. Najskuteczniej oczyszczały ścieki obiekty pracujące w technologii „constructed wetland".