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The Use of Hydrophytes for Additional Treatmnet of Municipal Sewage

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ABSTRACT
At the current stage of discharge and treatment of municipal sewage and other types of wastewater in the territory of Ukraine, traditional technologies of biological treatment in aero-tanks by the process of aerobic oxidation involving active silt characterized by low efficiency are largely used. It was established that biological treatment and additional treatment of sewage involving hydrophytes are efficient. The research on wastewater quality and the efficiency of sewage treatment was conducted in three phases: Phase 1 – "the quality before treatment", Phase 2 – "the quality after mechanical-biological treatment" at the existing municipal treatment plants, Phase 3 – "the quality after additional treatment by hydrophytes". In order to determine the efficiency of using hydrophytes additional treatment, *Eichhornia crassipes* (water hyacinth) and the perennial aquatic plant *Lemna minor* were planted in one treatment pond. The results of the experiment made it possible to determine high efficiency of using hydrophytes for additional sewage treatment. In particular, the efficiency of additional treatment in the treatment ponds removing the residue of suspended pollutants for 40 days was 32%, toxic salts – 13.0–23.0%, oil products – 30.0%, biogenic substances – 68.5–83.3%. It caused a drop in the values of chemical and biological oxygen demand for 5 days by 89.6% and 61.2%, respectively. The efficiency of sewage treatment removing toxic salts and oil products reached 97.7%, whereas in the case of mineral and organic pollutants – up to 99%. That contributed to a considerable increase in the wastewater quality by the criteria for fisheries. In particular, high nutritional value of *Eichhornia crassipes* and *Lemna minor* allowed obtaining 12.5 tons of hydrophyte wet mass that can be used as green manure, feeds for farm animals, poultry and fish.

Keywords: water quality, sewage, treatment systems, *Eichhornia crassipes*, *Lemna minor*, pollutants, water treatment.

INTRODUCTION

Increasing pollution of surface water and degradation of the natural state of water bodies caused a considerable reduction in the hydro network, water scarcity and its unsuitability for municipal needs, fisheries and irrigation without additional treatment. The main reasons for degradation of surface water are deterioration of water passages and runoff reduction (Pichura et al. 2018), discharge of untreated and insufficiently treated wastewater (Pichura et al. 2019, 2020), mass deforestation (Lisetskii et al. 2015, 2017), destruction of water conservation areas, reduction in natural lands, violation of agricultural technologies in water catchment areas (ploughing slopes and flood plains) (Pichura et al. 2017, Domaratskiy et al. 2020) resulting in more distinct manifestations of erosion processes (Dudiak et al. 2020, 2021), coastal abrasion, silting, as well as deterioration and destruction of water passages. Along with a continuous increase in anthropogenic loads there is a rise in the frequency of negative impacts of climate change on the state of water resources and water catchment basins (Pichura et al. 2020, 2021, Buryak et al. 2022), causing transformations of the structural-functional natural state of landscapes and aquastructures (Makarova et al. 2021).

Discharge of untreated and insufficiently treated wastewater causes anaerobic processes, decay and organic pollution, resulting in unsuitability of water bodies and water passages receiving sewage for water-use, leading to fish kill, water blooming and algae invasion. Sewage and industrial wastewater are hazardous; they are characterized by a high concentration of suspended pollutants, synthetic surface active agents (SSAA), high molecular organic compounds, heavy metal ions, radionuclides, oil products and other pollutants. Therefore, it is impossible to use them to satisfy the needs of fisheries and irrigation (Deffontis S. et al. 2013, Becouze-Lareure C. et al. 2016, Beckers L.-M. et al. 2018) etc.

At the current stage of discharge and treatment of municipal sewage and other types of wastewater in the territory of Ukraine, traditional technologies of biological treatment in aero-tanks in the process of aerobic oxidation involving active silt are used. These technologies have been used since the 1950–60s, first of all, to treat highly concentrated wastewater. They have low efficiency and a number of disadvantages, in particular: worse efficiency of treatment under uneven passage of wastewater and concentrated pollution, slow treatment process resulting from low temperature or a rapid change in temperature, pH, substances toxic for active ill, incompliance of treated water quality with the accepted standards of water use, a high level of excessive silt, requiring additional expenses for utilization (Pichura V.I. 2020). In particular, the existing biological treatment plants do not correspond to the modern requirements for nature-conserving measures as well as do not ensure appropriate water treatment and compliance with the threshold limit value for discharge of pollutants into natural water bodies. Therefore, development, approbation and practical use of efficient and cost-saving technologies for treating wastewater become topical.

Application of biological technologies of treatment and additional treatment of sewage using hydrophytes is an efficient solution (Carbiner R. et al. 1990, Eidab E.M. et al. 2021, Mònica E. et al. 2022). They improve chemical properties of water and are a biological filter of treating water resources (Zimmles Y. et al. 2006, Wangb F. et al. 2021, Imron M.F. et al. 2021). Under the conditions of increasing anthropogenic load on water resources, ecological-biological and economic substantiation of using higher aquatic plants to ensure biological treatment of sewage is very important. In particular, the research on practical use of hydrophytes is of significant economic interest for treatment and additional treatment of sewage in order to reuse wastewater and reduce loads on surface water.

MATERIAL AND METHODS

The research object was the process of improving wastewater quality in Kherson by using higher aquatic plants. The research on wastewater quality and sewage treatment efficiency was conducted in three phases: Phase 1 – "the quality before treatment", Phase 2 – "the quality after mechanical-biological treatment" at the municipal water treatment plants, Phase 3 – "the quality after additional treatment by hydrophytes" (Fig. 1).

Every day, the municipal water treatment plants covering the area of 85.2 ha treat 45–50 thous.m^3 of wastewater, flowing to the treatment plants through 17 pumping stations. The total length of the wastewater networks is 297 km. The municipal wastewater treatment plants were constructed in 1975, they have a two-level scheme of wastewater treatment: mechanical treatment – bar grating, sand traps and preliminary settling tanks holding heavy pollutants and treat sewage to 35–40%; biological treatment – wastewater treatment by bio-organisms, the viability of which is maintained with oxygen supply (aero-tanks), ensuring water treatment to 90% and more. Further, water passes to secondary settling tanks, and then it is discharged into the right arm of the Dnipro river – the Koshova river through the Virovchyna river.

Over the past 25 years, reconstruction of the water treatment plants was not performed, which caused a drop in the efficiency of sewage treatment in Kherson. Therefore, in order to conduct the third phase of the research on the results of additional sewage treatment, *Eichhornia crassipes* and the perennial aquatic plant *Lemna minor* were planted in one pond. The total area of four treatment ponds is 17.2 ha with the capacity of additional sewage treatment of about 250 thous. m^3. The experiment of the third phase of the research was carried out in an individual treatment pond covering the area of 1.0 ha and 1.5 m deep with the actual volume of sewage of 13000 m^3. The placement of hydrophytes in the sewage treatment pond was calculated as 1 plant *Eichhornia crassipes* per 5 m^2 with the average weight of wet mass of 62.0±10.0 g and additional planting *Lemna minor* of about 10% of *Eichhornia crassipes* weight. The total weight of hydrophyte placement per 1.0 ha of the pond was about 136.5 kg. The research was conducted in summer months, because in July–August the level of water consumption and sewage reaches the maximum. The water temperature in secondary settling tanks

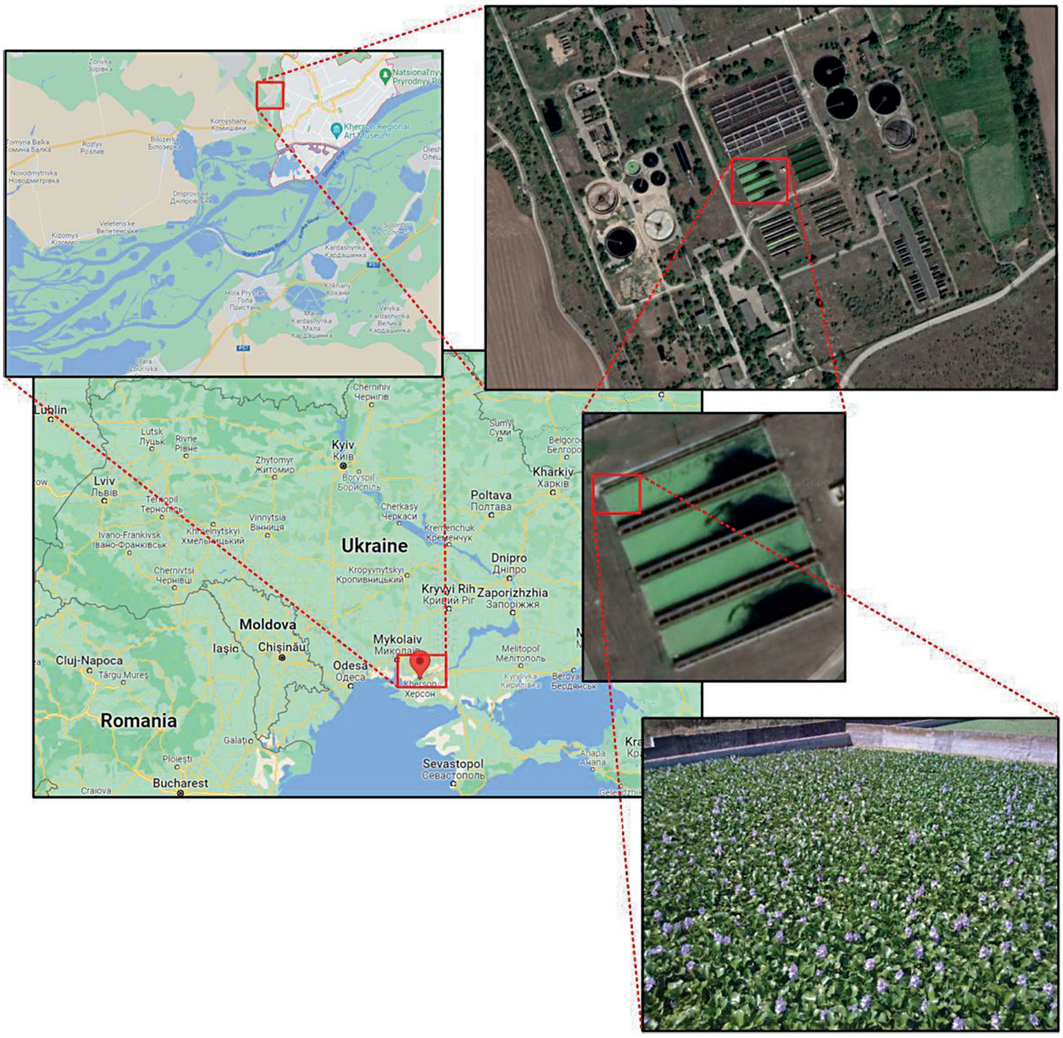

Figure 1. Location of Kherson water treatment plants and research treatment ponds for additional water treatment by hydrophytes

was 26.0–27.5°C in June, 27.0–34.0°C in July and 28.2–34.5°C in August.

The water quality in the three phases was determined during 2016–2021 by the indices of changes in its hydro-chemical properties. The efficiency of sewage treatment at the wastewater treatment plants was determined by comparing its quality before transportation to the treatment plants and after discharge from them according to the method of control over wastewater quality [Sheludchenko B.A. 2001]. The complex evaluation of wastewater quality was performed using different methods, in compliance with the standards of water quality for surface water bodies in Ukraine by the Threshold Limit Value (*TLV*) for fisheries (Maximum permissible values of water quality indicators for fishery reservoirs… 1990, Ecological assessment of surface water quality of land and estuaries of Ukraine... 1994). In order to process and analyze the incoming data, the authors used the licensed software STATISTICA Advanced + QC for Windows v.10 Ru.

RESULTS AND DISCUSSION

Domestic and industrial wastewater is discharged by gravity through the Kherson sewage system, its capacity being about 250 thous. m^3 per day. About 60% of the municipal sewage system is in unsatisfactory technical condition that causes its systematic breakdown, outflow and redistribution of sewage in the groundwater that is hydraulically connected with neogene horizons in the municipal water supply. In order to maintain satisfactory condition of the sewage system, it is necessary to renew at least 5% (45 $km \cdot year^{-1}$) of its length annually, according to the actual data, in 2016–2021 about 0.8% of the sewage system were renewed annually. Moreover, in 2016–2021, daily volumes of sewage for the municipal treatment plants (Komyshany) were 45–50 thous. m^3, which were discharged as relatively treated wastewater into the right arm of the Dnipro through biological ponds.

A negative impact of this discharge on the state of the hydro-ecosystems of the Low Dnipro was identified; it is worsened by unsatisfactory technical conditions of the treatment plants, in particular, untimely treatment of the biological ponds causing discharge of a considerable amount of polluted silt, as a result, about 400 tons of surface active substances, oxides of nitrogen, sulfur, phosphorus, oil products, etc. enter the river.

It was established that in 2016–2021 the mean value of the individual indices of hydro-chemical properties of sewage (Table 1) discharged immediately into the water area of the Virovchyna river and redistributed to the Koshova and the Dnipro river exceeded the *TLV* by the criteria for fisheries: the content of suspended pollutants – 4.2 times, phosphates – 3.6 times; dry residue – 1.3 times; sulfates – 1.7 times; chlorides – 1.2 times; sodium+potassium – 2.6 times; ammonium nitrogen – 3.8 times; oil products – 2.0 times.

A significant characteristic of a change in wastewater quality is chemical oxygen demand (COD_5) and biological oxygen demand for 5 days (BOD_5): the value of COD_5 (TLV = 2.0 $mgO_2 \cdot dm^{-3}$) before treatment – 400.0±52.3 $mgO_2 \cdot dm^{-3}$, after treatment 54.2±9.8 $mgO_2 \cdot dm^{-3}$, the treatment efficiency – 86.45%; the value of BOD_5 (TLV = 2.0 $mgO_2 \cdot dm^{-3}$) before treatment – 200.0±34.5 $mgO_2 \cdot dm^{-3}$, after treatment – 14.50±2.17 $mgO_2 \cdot dm^{-3}$, the treatment efficiency – 92.75%.

The change in hydrochemical properties of sewage is explained by distinct seasonal dynamics, characterized by a change in the volume of water consumption in the houshold activities. The release of dry residues (salt, soil comonents and biogenic-detrital particles) to the treatment palnts in autumn is 1.4 times lesser than in summer. Therefore, the efficiency of sewage treatment depends on the number of pollutants entering the treatment plants. Therefore, the efficiency of the treatment systems in Kherson is 50.0–97.0% by the difference of the indices of hydrochemical properies of trasported and discharged sewage (Table 2).

The results of the research on hydro-chemical properties of treated sewage at the place of discharge indicate to a considerable reduction in pollutants which come with sewage to the treatment systems. However, at the place of discharge of the river water area, hydrochemical properties of sewage exceed the *TLV* for fisheries 4 times by some indices.

In order to reduce the rate and volume of pollutants brought with sewage of Kherson in summer and prevent deterioration of the ecological

Table 1. Hydro-chemical properties of sewage in the place of discharge in 2016–2021

Season and years		Suspended pollutants, $mg \cdot dm^{-3}$	pH	Dry residue, $mg \cdot dm^{-3}$	Sulfates, $mg \cdot dm^{-3}$	Chlorides, $mg \cdot dm^{-3}$	Phosphates, $mg \cdot dm^{-3}$	Calcium, $mg \cdot dm^{-3}$	Magnesium, $mg \cdot dm^{-3}$	Sodium + potassium, $Mg \cdot dm^{-3}$	Ammonium nitrogen, $mg \cdot dm^{-3}$	Nitrate nitrogen, $mg \cdot dm^{-3}$	Oil products, $mg \cdot dm^{-3}$
TLV by the criteria for fisheries													
TLV		20	6.5-8.5	1000	100	300	3.5	180	50	120	0.50	40	0.05
Before treatment	$\bar{x}$	2327	8.2	32568	5733	6236	51.7	151.2	32.3	1226.7	49.2	186.7	0.12
	σ	441.3	0.24	4501	529	350	6.8	70,5	14.8	271.8	10.8	41.3	0.04
After treatment	$\bar{x}$	84.0	8.5	1300	168	365.7	12.6	150,3	4.4	313.9	1.9	25.7	0.10
	σ	12.5	0.3	207.0	20.8	43.6	1.8	47,9	1.4	69.6	0.8	12.3	0.04
+/-		-2243	0.35	-31268	-5565	-5870	-39.1	-0,87	-27.9	-912.8	-47.3	-161	-0.02
TLM excess		4.2	–	1.3	1.7	1.2	3.6	–	–	2.6	3.8	–	2.0

Table 2. The efficiency of sewage treatment at the treatment plants, %

Season and years	Suspended pollutants, $mg \cdot dm^{-3}$	Temperature, c°	pH	Mineralization (dry residue), $mg \cdot dm^{-3}$	Sulfates, $mg \cdot dm^{-3}$	Chlorides, $mg \cdot dm^{-3}$	Phosphates, $mg \cdot dm^{-3}$	Ammonium nitrogen, $mg \cdot dm^{-3}$	Nitrate nitrogen, $mg \cdot dm^{-3}$	Oil products, $mg \cdot dm^{-3}$
June 2020	55	0	1.22	95	97	94	75	95	95	58
July 2020	69	0	0	97	97	94	78	95	92	8
August 2020	65	0	0	97	97	95	75	96	92	0
June 2021	68	0	1.22	96	96	95	77	93	89	75
July 2021	67	0	0	95	96	94	78	92	82	50
August 2021	57	0	0	95	96	93	77	95	83	92

condition of the river hydro-systems, planting *Eichhornia crassipes* and the perennial aquatic plant *Lemna minor* in the treatment pond of secondary aeration is suggested for additional sewage treatment. *Eichhornia crassipes* and *Lemna minor* are capable of consuming biogenic substances (nitrogen, phosphorus) and accumulate heavy metals (lead, mercury, copper, cadmium, nickel, cobalt, tin, manganese, iron, zinc and chromium), radionuclides (cesium, strontium, cerium, cobalt etc). Biochemical processes result in oxidation-reduction reactions in the root system of Eichhronia that determine transformation of high molecular compounds into low molecular compounds and isolation of necessary chemical nutrients. Hydrophytes are well adapted to the environmental conditions and can intensively transform organic and non-organic compounds from water solutions. At the same time, being concentrated in large amounts, they can effectively mineralize detritus and control the number of microorganisms. Thus, the use of hydrophytes will increase the efficiency of additional biological treatment of sewage and ensure the growth of production of fodder resources.

The efficiency of using *Eichhornia crassipes* and *Lemna minor* for additional sewage treatment was examined in the summer months of 2016–2021, the air temperature ranged from 35.0°C in June to 46.0°C in July and August, the water temperature in the open water bodies ranged from 26.0°C in June to 34.0°C in July and August. The rate of sewage treatment in the treatment ponds was examined over 40 days, with the frequency of water collection to register the values of hydro-chemical indices of water quality of every 10 days (Table 3).

It was determined that the content of pollutants during the entire period of the research on additional treatment tended to decrease. In particular, the efficiency of additional treatment of the residue of suspended pollutants in the treatment ponds for 40 days was 32% – from 84.0±12.5 mg·dm^{-3} (4.20 TLV) to 57.1±8.5 mg·dm^{-3} (2.86 TLV). The value of pH was 8.05–8.50 that complied with the TLV with slight alkalinity. The contents of sulfates and chlorides in the period of additional treatment with the use of hydrophytes decreased by 23.0% and 13.0%, respectively, and were 1.3TLV of sulfates and 1.06 TLV of chlorides in the treated water discharged into the river water area.

High efficiency of using *Eichhornia crassipes* with *Lemna minor* was registered in additional sewage treatment removing biogenic substances. Uncontrolled invasion of increased content of biogenic substances with sewage into surface water is one of the main problems causing deterioration of the trophic status of the water area of water bodies and rivers and the invasion of blue-green algae. Additional treatment resulted in a reduction in the content of phosphates in sewage by 83.3% – from 12.6±1.8 mg·dm^{-3} (3.60 TLV) to 2.1±0.3 mg·dm^{-3} (0.60 TLV), that of ammonium nitrogen

Table 3. Dynamics of the values of hydro-chemical indices of wastewater quality in the treatment ponds with additional treatment by *Eichhornia crassipes* and *Lemna minor*

Water quality indexes	Duration of treatment, days					Treatment efficiency for 40 days, %
	0	10	20	30	40	
Suspended pollutants, mg·dm^{-3}	84.0±12.5	75.9±11.3	74.5±11.0	60.9±9.0	57.1±8.5	32.0
pH	8.50±0.30	8.05±0.28	8.25±0.29	8.30±0.29	8.30±0.29	–
Dry residue, mg·dm^{-3}	1300±207	1245±198	1210±192	1170±185	1120±178	13.8
Sulfates, mg·dm^{-3}	168.0±20.8	137.1±16.9	135.3±16.7	132.8±16.4	129.4±16.0	23.0
Chlorides, mg·dm^{-3}	365.7±43.6	341.9±40.5	330.1±39.5	323.9±38.6	318.2±37.9	13.0
Phosphates, mg·dm^{-3}	12.6±1.8	11.8±1.7	8.1±1.2	5.9±0.8	2.1±0.3	83.3
Calcium, mg·dm^{-3}	150.3±47.9	138.7±44.2	136.0±43.3	133.7±42.6	129.6±41.3	13.8
Magnesium, mg·dm^{-3}	4.40±1.40	4.26±1.37	4.18±1.33	4.01±1,27	3.92±1.23	10.9
Sodium + potassium, mg·dm^{-3}	313±69.6	291±64.7	282±62.6	275±61,2	269±59.9	14.0
Ammonium nitrogen, mg·dm^{-3}	1.90±0.80	1.22±0.51	0.83±0.31	0.62±0,24	0.46±0.20	75.8
Nitrate nitrogen, mg·dm^{-3}	25.7±12.3	18.3±8.8	14.9±7.1	10.2±4.9	8.1±3.9	68.5
Oil products, mg·dm^{-3}	0.10±0.04	0.09±0.04	0.07±0.03	0.07±0.03	0.07±0.03	30.0
COD_5, mgO_2·dm^{-3}	54.20±9.80	38.8±7.02	21.68±3.92	12.85±2.32	5.62±1.02	89.6
COD_5, mgO_2·dm^{-3}	14.50±2.17	13.9±2.08	6.83±1.02	6.10±0.91	5.62±0.84	61.2

– by 75.8% – from 1.90±0.80 mg·dm^{-3} (3.80 TLV) to 0.46±0.20 mg·dm^{-3} (0.92 TLV), that of nitrate nitrogen – by 68.5% – from 25.7±12.3 mg·dm^{-3} (0.64 TLV) to 8.1±3.9 mg·dm^{-3} (0.20 TLV). In the treatment ponds there was a low level of additional treatment by hydrophytes removing the following salts: the content of magnesium fell by 10.9% being 0.08 TLV, that of calcium – by 13.8% being 0.72 TLV, that of sodium+potassium – by 14.0% being 2.24 TLV. The content of oil products dropped by 30.0%, reaching 1.4 TLV.

One of the main indices characterizing the level and dynamics of treatment or self-treatment of polluted wastewater is chemical oxygen demand. It is determined by the amount of oxygen for oxidation of chemical pollutants in the unit of water volume for a particular time (5 days — COD_5, 10 days — COD_{10} etc). The highest values of oxidation are characteristic of water with a high content of biogenic substances. Chemical oxygen demand for 5 days fell by 89.6% – from 54.20±9.80 mgO_2·dm^{-3} (27.1 TRLV) to 5.62±1.02 mgO_2·dm^{-3} (2.81 TLV) due to additional treatment by hydrophytes. At the time of discharging wastewater into the river water area, the value of COD_5 was characterized on the border between the classes «medium (5.0–10.0 mgO_2·dm^{-3}) – small (2.0–5.0 mgO_2·dm^{-3})» of water oxidation. Along with COD_5, biochemical oxygen demand (BOD) is, another important index of the efficiency of wastewater treatment is characterized by the amount of dissolved oxygen used by aquatic organisms for aerobic decomposition of organic substances entering water to grow, reproduce and develop biomass. In particular, the value of BOD depends on the presence of organic pollutants in water. An increase in the index of BOD causes deficiency of dissolved oxygen in water that has a negative impact on the living conditions of aquatic organisms. Due to additional treatment by hydrophytes, biochemical oxygen demand for 5 days dropped by 61.2% – from 14.50±2.17 mgO_2·dm^{-3} (7.25 TLV) to 5.62±0.84 mgO_2·dm^{-3} (2.81 TLV) on the border between the classes «medium (5.0–10.0 mgO_2·dm^{-3}) – small (2.0–5.0 mgO_2·dm^{-3})» of biological oxygen demand. The rates of additional sewage treatment by hydrophytes removing pollutants in the treatment ponds are mathematically presented in Table 4.

Due to combined sewage treatment using the existing system of mechanical-biological treatment and additional treatment by hydrophytes *Eichhornia crassipes* and *Lemna minor* during the period of maximum water consumption and water discharge, the efficiency of sewage treatment removing toxic salts and oil products (Fig. 2) was 14.0–97.7%, whereas that of removing mineral and organic pollutants (Fig. 3) – 96.0–99.0%.

The research results made it possible to determine that the phytomass of a single *Eichhornia crassipes* plant increased by 114.5±8.6 grams for 40 days. It resulted from a high air temperature in the summer months and sewage with a high concentration of biogenic substances transported to the treatment ponds for additional treatment, which created good growing conditions for hydrophytes. The reproduction rate of *Eichhornia crassipes* is mathematically described with the function $y = 0.5e^{0.3466t}$. The total bio-productivity of hydrophytes in the treatment pond for 40 days

Table 4. Functions of the rate of sewage treatment by hydrophytes *Eichhornia crassipes* та *Lemna minor*

Indexes of water quality	Function	Correlation, *r*	Determination, r^2
Suspended pollutants, mg·dm^{-3}	$y = -0.688t + 84.24$	0.974	0.948
Dry residue, mg·dm^{-3}	$y = -4.35t + 1296$	0.997	0.995
Sulfates, mg·dm^{-3}	$y = 0.0388t^2 – 2.3664t + 164.58$	0.946	0.895
Chlorides, mg·dm^{-3}	$y = 0.0299t^2 – 2.3243t + 364.53$	0.995	0.991
Phosphates, mg·dm^{-3}	$y = -0.269t + 13.48$	0.984	0.968
Calcium, mg·dm^{-3}	$y = 0.011t^2 – 0.904t + 149.14$	0.975	0.951
Magnesium, mg·dm^{-3}	$y = -0.0121t + 4.396$	0.995	0.990
Sodium + potassium, mg·dm^{-3}	$y = 0.0243t^2 – 2.0114t + 311.66$	0.993	0.987
Ammonium nitrogen, mg·dm^{-3}	$y = 0.0009t^2 – 0{,}0697t + 1.8763$	0.998	0.996
Nitrate nitrogen, mg·dm^{-3}	$y = 0.0066t^2 – 0.6987t + 25.429$	0.996	0.993
Oil products, mg·dm^{-3}	$y = -0.0008t + 0.096$	0.894	0.800
COD_5, mgO_2·dm^{-3}	$y = 1.7593t^2 – 22.867t + 75.878$	0.998	0.997
BOD_5, mgO_2·dm^{-3}	$y = 0.47t^2 – 5.376t + 20.348$	0.936	0.877
t – time of sewage treatment removing pollutants, day			

of additional sewage treatment was more than 12.5 tons of wet mass, i.e. 1.25 kg·m^{-2}.

It was established that the herbage content of *Eichhornia crassipes*, planted for additional sewage treatment was characterized by high moisture content (94–88.9%), proteins – 20–30 kg·ton^{-1} of herbage, nitrogen – 20–35 kg·ton^{-1}, phosphorous – 12–17 kg·ton^{-1}, carotene – 35–40 kg·ton^{-1}. The *Eichhornia crassipes* and *Lemna minor* hydrophytes are used as green manure to provide animal husbandry and fisheries with feeds.

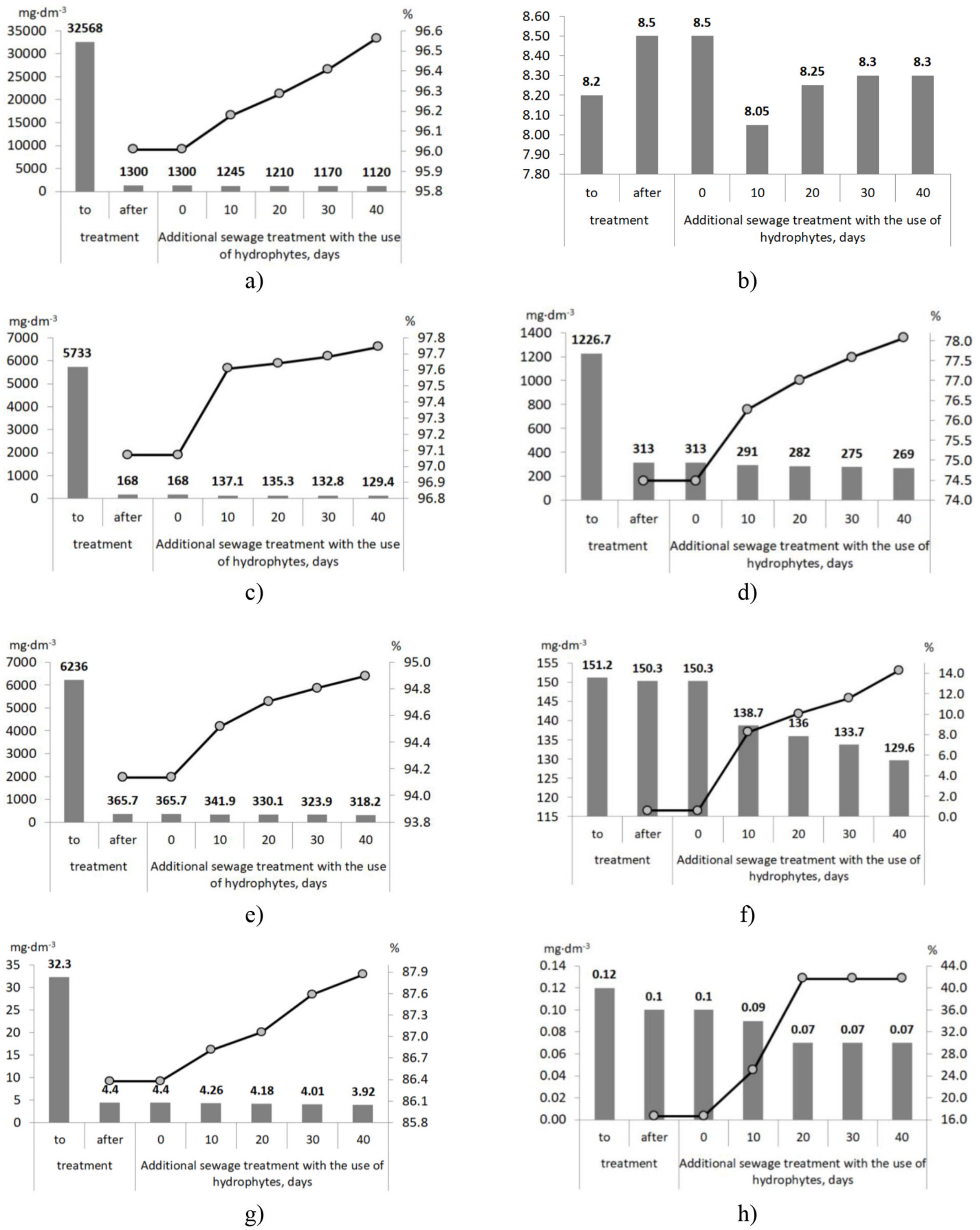

Figure 2. Combined sewage treatment removing salts and oil products: a) dry residue; b) pH; c) sulfates; d) sodium + potassium; e) chlorides; f) calcium; g) magnesium; h) oil products

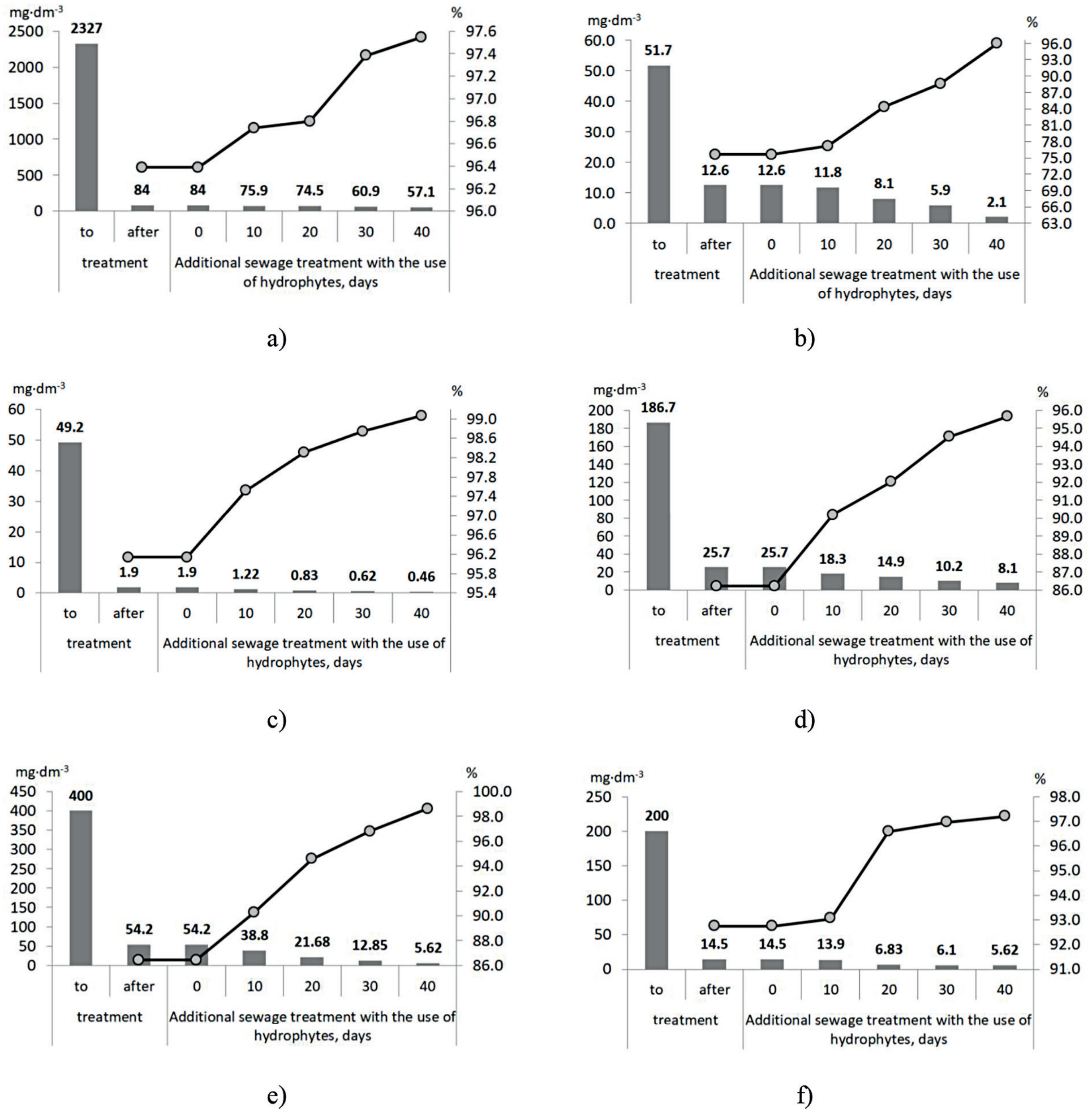

Figure 3. Combined sewage treatment removing mineral and organic pollutants: a) suspended pollutants; b) phosphates; c) ammonium nitrogen; d) nitrate nitrogen; e) COD_5; f) BOD_5

CONCLUSIONS

The research results prove the high efficiency of using *Eichhornia crassipes* and *Lemna minor* for additional sewage treatment. The use of hydrophytes is efficient in summer months. Summer temperatures in the Steppe zone, ranging from 35.0 to 46.0°C, ensure sewage temperature from 26.0 to 34.5°C in the treatment ponds, which creates the conditions for hydrophyte development and their intake of pollutants from water. It was established that the existing treatment system of municipal sewage does not create proper conditions for treating the sewage entering the river water area. The content of pollutants in the sewage after treatment by the criteria for fisheries exceeded the level of the accepted concentration, in particular: the content of suspended pollutants – 4.2 times, phosphates – 3.6 times; dry residue – 1.3 times; sulfates – 1.7 times; chlorides – 1.2 times; sodium+potassium – 2.6 times; ammonium nitrogen – 3.8 times; oil products – 2.0 times. Experimental placement of *Eichhornia crassipes* and *Lemna minor* in the treatment pond resulted in an increase in the efficiency of additional sewage treatment. In particular, the efficiency of additional treatment removing the residue of suspended pollutants in the treatment ponds for 40 days was 32%, toxic salts – 13.0–23.0%, oil products – 30.0%, biogenic substances – 68.5–83.3%. It resulted in a drop in the values of chemical and biological oxygen demand for 5 days – by 89.6% and 61.2%, respectively. The efficiency of sewage treatment removing toxic salts and oil products reached 97.7%, mineral and organic pollutants – up to 99.0%, which contributed to a considerable increase in the wastewater quality by the criteria for fisheries. In particular, taking into consideration a high nutritional value of *Eichhornia crassipes* and *Lemna minor*, 12.5 tons of hydrophyte wet mass were obtained to be used as green manure, feeds for farm animals, poultry and fish.

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