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ВОДА ЗІ СТАНЦІЙ ОЧИЩЕННЯ СТІЧНИХ ВОД І ЇЇ ВИКОРИСТАННЯ В СІЛЬСЬКОМУ ГОСПОДАРСТВІ

Через невірний розподіл водних ресурсів в сільськогосподарських районах Болгарії та Словаччини існує зростаюча нестача економічно ефективних джерел води для зрошення з підходящими показниками якості. Негативний водний баланс обох країн обмежує розвиток зрошуваного землеробства. В обох країнах були встановлені численні станції для біологічної очистки стічних вод, так як недостатньо очищена вода із-за високого вмісту органічних забруднень погіршує свої якісні споживчі характеристики. Використання очищених стічних вод для зрошення сільськогосподарських полів є не тільки одним з варіантів для інтенсифікації сільського господарства, а й для охорони вод від забруднення. Основна мета даної роботи є розробка та впровадження системи оцінки та використання в сільському господарстві очищеної води, що надходить зі станцій очищення стічних вод. Задачі - рішення конкретних теоретичних і практичних задач, а також оцінка ефекту очищеної води в експериментах, розробка та впровадження системи для агроекологічної оцінки очищеної води. Система допомагає вирішити деякі екологічні та економічні проблеми суспільства, які тісно пов'язані зі стійким розвитком сільського господарства.

Ключові слова: *очищені стічні води, зрошуване сільське господарство, родючість ґрунту, Болгарія, Словаччина.*

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ВОДА СО СТАНЦИЙ ОЧИСТКИ СТОЧНЫХ ВОД И ЕЁ ИСПОЛЬЗОВАНИЕ В СЕЛЬСКОМ ХОЗЯЙСТВЕ

Из-за неправильного распределения водных ресурсов в сельскохозяйственных районах Болгарии и Словакии существует растущая нехватка экономически эффективных источников воды для орошения с подходящими показателями качества. Отрицательный водный баланс обеих стран ограничивает развитие орошаемого земледелия. В обеих странах были установлены многочисленные станции для биологической очистки сточных вод, так как при этом недостаточно очищенная вода из-за высокого содержания органических загрязнений ухудшает свои качественные потребительские характеристики. Использование очищенных сточных вод для орошения сельскохозяйственных полей является не только одним из вариантов для интенсификации сельского хозяйства, но и для охраны вод от загрязнения. Основная цель данной работы является разработка и внедрение системы оценки и использования в сельском хозяйстве очищенной воды, поступающей со станций очистки сточных вод. Задачи - решение конкретных теоретических и практических задач, а также оценка эффекта очищенной воды в экспериментах, разработка и внедрение системы для агроэкологической оценки очищенной воды. Система помогает решить некоторые экологические и экономические проблемы общества, которые тесно связаны с устойчивым развитием сельского хозяйства.

Ключевые слова: *очищенные сточные воды, орошаемое сельское хозяйство, плодородие почвы, Болгария, Словакия.*

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WATER FROM WASTEWATER TREATMENT STATIONS AND ITS USE IN AGRICULTURE

Abstract. *There is an increasing shortage of economically effective water sources for irrigation with suitable quality indicators in agricultural regions of Bulgaria and Slovakia because of irregular allocation of water sources. In the same time, numerous stations for biologically treated wastewater were established in both countries. The treated water due to its high content of organic pollution worsens the quality characteristics of the intakes, mostly river streams. The negative water balance of both countries limits the development of the irrigated agriculture. The usage of treated wastewater for irrigation in agricultural fields of villages is an option not only for the intensification of the agriculture but also for the protection of the water flows from pollution, as well. The fundamental goal of this work is development and implementation of a system for assessment and usage in agriculture of the treated water coming from wastewater treatment stations. The objectives are the solutions of specific theoretical and practical tasks, as well as assessment of the treated water effect on products ingreenhouses' experiments, and development and implementation of the system for agro-ecological assessment of the treated water. The system helps solving some environmental and economic problems of the society, which are strongly related to the sustainable agricultural development.*

Keywords: *treated wastewater, irrigated agriculture, soil fertility, Bulgaria, Slovakia.*

Introduction. Dozens of stations for biologically treated wastewater have been established for recent years. The final result of the process of biological purification is sludge and treated water. All too often, the treated water flows into water basins instead of using it for irrigation and soil improvement. Development of technological solutions for making use of treated water in agriculture requires assessment of the characteristics of treated water from the agricultural crops' irrigation point of view. For using specific water for irrigation, it should satisfy some quality indicators as chemical structure, availability of gases, content of organic substances and bacteria, muddiness, temperature, etc. Those indicators depend on salt sustainability of the cultivated crops, chemical structure and water permeability of the soil, drainage of the ground, characteristics of the rainfalls, background content of heavy metals, meteorological and hydro-geological circumstances, irrigation technology, applied agriculture techniques, etc. The suitability of the treated water for irrigation can be determined based on the results from chemical analysis, vegetation and field experiments, as well as comparing various crops irrigated with clean and treated wastewater during long period. The research studies of Panoras and Ilias (Panoras, A., 2001, 2000, 1999, 1998) have been used as a basis of this research carried out.

The main aim of the study is development of a system for usage in agriculture of the treated water coming from wastewater treatment stations. The specific theoretical and practical tasks are assessment of the treated water effect on a product during the greenhouse experiments, development and implementation of the technology for agro-ecological assessment of the treated water.

Materials and Methods. For assessment of the suitability of the treated water originated from the wastewater treatment stations for irrigation, water characteristics are taken into consideration as well as data from vegetation and field experiments. These data show factors of the water-soil-plant-fertilizer system and their mutual impact. The experiments have been carried out using treated water originated from Sofia City Wastewater Treatment Station (SCWWTS).

Characterization of the treated wastewater from agricultural crops' irrigation point of view. As a basis for assessment of water from the point of view how it is suitable for irrigation in agriculture, we studied the daily average and monthly average samples. Monitoring on the water characteristics is performed, i.e. 3 daily twenty-four-hour samples, samples taken every hour (Table 1, 2 and 3), as well as monthly monitoring on the water characteristics, i.e. 12 daily samples which were taken between 9 am and 1 pm (Table 4.).

These data are a basis for determination of the quantity of bio-gene elements and of the heavy metals, which will be accumulated during an annual usage of the treated wastewater for irrigation of agricultural crops.

1. Heavy metals availability in mg/l treated wastewater samples taken at SCWWTS during the first day

Sample taking, hour	Zn	Cu	Ni	Cr	Co	Mn	Pb	Cd	As
9 am	0.062	0.011	0.088	0.008	0.036	0.096	0.051	0.014	0.011
11 am	0.054	0.032	0.120	0.005	0.041	0.174	0.037	0.011	0.007
1 pm	0.046	0.022	0.110	0.024	0.022	0.082	0.029	0.005	0.008
3 pm	0.012	0.013	0.093	0.011	0.025	0.074	0.034	0.017	0.009
5 pm	0.013	0.026	0.076	0.027	0.024	0.115	0.046	0.021	0.007
7 pm	0.052	0.025	0.084	0.014	0.033	0.126	0.054	0.014	0.010
9 pm	0.033	0.014	0.092	0.022	0.027	0.058	0.039	0.017	0.011
11 pm	0.046	0.014	0.064	0.033	0.031	0.066	0.043	0.022	0.008
1 am	0.035	0.014	0.053	0.015	0.045	0.072	0.061	0.014	0.012
3 am	0.062	0.025	0.062	0.014	0.037	0.059	0.029	0.025	0.010
5 am	0.015	0.025	0.043	0.010	0.038	0.105	0.038	0.026	0.011
7 am	0.024	0.015	0.028	0.010	0.041	0.094	0.044	0.031	0.008
Average	0.038	0.020	0.076	0.016	0.033	0.093	0.042	0.018	0.009

2. Heavy metals availability in mg/l treated wastewater samples taken at SCWWTS during the second day

Sample taking, hour	Zn	Cu	Ni	Cr	Co	Mn	Pb	Cd	As
9 am	0.009	0.026	0.054	0.025	0.022	0.059	0.026	0.026	0.009
11 am	0.010	0.033	0.110	0.028	0.025	0.085	0..35	0.022	0.010
1 pm	0.012	0.027	0.068	0.017	0.017	0.079	0.014	0.014	0.006
3 pm	0.010	0.026	0.077	0.022	0.042	0.112	0.022	0.022	0.007
5 pm	0.012	0.044	0.093	0.024	0.038	0.153	0.015	0.017	0.007
7 pm	0.011	0.035	0.086	0.017	0.032	0.072	0.010	0.017	0.008
9 pm	0.008	0.035	0.052	0.021	0.035	0.058	0.015	0.026	0.008
11 pm	0.011	0.037	0.076	0.008	0.036	0.063	0.016	0.031	0.011
1 am	0.012	0.035	0.095	0.011	0.043	0.071	0.027	0.014	0.009
3 am	0.012	0.022	0.027	0.012	0.051	0.066	0.014	0.009	0.008
5 am	0.014	0.025	0.053	0.011	0.038	0.123	0.015	0.012	0.009
7 am	0.022	0.024	0.048	0.010	0.035	0.138	0.014	0.014	0.008
Average	0.012	0.031	0.070	0.017	0.035	0.090	0.019	0.019	0.008

3. Heavy metals availability in mg/l treated wastewater samples taken at SCWWTS during the third day

Sample taking, hour	Zn	Cu	Ni	Cr	Co	Mn	Pb	Cd	As
9 am	0.072	0.031	0.075	0.005	0.027	0.067	0.017	0.017	0.010
11 am	0.025	0.035	0.089	0.010	0.038	0.058	0.021	0.018	0.009
1 pm	0.034	0.035	0.114	0.012	0.055	0.060	0.018	0.025	0.011
3 pm	0.012	0.025	0.105	0.013	0.048	0.063	0.014	0.016	0.012
5 pm	0.044	0.041	0.075	0.017	0.029	0.107	0.038	0.008	0.008
7 pm	0.037	0.045	0.083	0.029	0.061	0.092	0.051	0.006	0.008
9 pm	0.063	0.045	0.066	0.034	0.043	0.096	0.037	0.011	0.008
11 pm	0.065	0.045	0.066	0.034	0.043	0.096	0.037	0.011	0.008
1 am	0.042	0.035	0.038	0.019	0.038	0.068	0.036	0.012	0.008
3 am	0.024	0.046	0.057	0.025	0.044	0.077	0.021	0.021	0.009
5 am	0.022	0.033	0.025	0.038	0.052	0..79	0.017	0.015	0.008
7 am	0.013	0.022	0.067	0.009	0.038	0.068	0.014	0.021	0.008
Average	0.038	0.036	0.070	0.019	0.044	0.080	0.027	0.015	0.009

4. Chemical characteristics of the treated wastewater coming from SCWWTS by days

Sample taking date	NH_4^+- N, mg/l	Total N, mg/l	Total P, mg/l	Total K, mg/l	Fe, mg/l	Pb, mg/l	Cd, mg/l	Mn, mg/l	Zn, mg/l	Cu, mg/l	Ni, mg/l	Cr, mg/l	As, mg/l	Hg, mg/l	Co, mg/l	pH directly
19 May	5	12	2.8	0.5	0.11	0.003	0.001	0.10	0.08	0.003	0.001	0.001	0.009	0.004	0.002	8.40
21 May	7	14	3.0	0.7	0.19	0.002	0.001	0.11	0.07	0.004	0.008	0.004	0.011	0.004	0.002	8.57
23 May	8	18	2.8	0.7	0.20	0.002	0.001	0.12	0.06	0.005	0.007	0.005	0.007	0.003	0.001	8.57
26 May	6	24	2.1	0.4	0.10	0.001	0.001	0.15	0.07	0.005	0.001	0.001	0.009	0.006	0.001	8.45
28 May	10	16	3.2	0.7	0.27	0.003	0.001	0.15	0.07	0.008	0.006	0.002	0.010	0.005	0.001	7.85
30 May	11	18	1.9	0.9	0.19	0.002	0.001	0.16	0.08	0.008	0.001	0.006	0.008	0.011	0.001	7.68
2 June	9	18	1.2	0.7	0.28	0.020	0.001	0.14	0.08	0.010	0.011	0.012	0.007	0.004	0.004	7.75
4 June	11	18	2.8	0.8	0.25	0.024	0.002	0.16	0.12	0.062	0.058	0.058	0.014	0.003	0.015	7.20
6 June	13	16	1.8	0.8	0.26	0.019	0.001	0.19	0.07	0.012	0.013	0.003	0.022	0.006	0.004	8.42
11 June	10	18	06	0.8	0.20	0.042	0.005	0.19	0.18	0.048	0.010	0.011	0.046	0.004	0.002	7.38
12 June	7	13	0.4	0.7	0.18	0.036	0.004	0.21	0.19	0.130	0.035	0.063	0.075	0.009	0.026	7.20
13 June	10	21	0.4	0.7	2.69	0.057	0.011	0.20	0.33	0.064	0.016	0.016	0.117	0.018	0.012	7.20
Average	8.75	16.3	1.92	0.7	0.41	0.018	0.002	0.16	0.18	0.030	0.015	0.015	0.028	0.007	0.006	7.92

Usage of treated water originated from wastewater treatment stations for

irrigation at vegetation experiments. The research has been carried out with some basic vegetables and forage plants. Half of the variants have been irrigated with treated wastewater; the others were irrigated with clean water. The experiments have been performed in several series of which some have been carried out with fertilizers and without fertilizers. The vegetation experiments have been performed on alluvial meadow soil taken from the area of SCWWTS. The analytical data of average soil samples show that the content of total nitrogen is 0.147%, of total phosphorus is 0.210%, and of total potassium is 0.498%.The soil is relatively rich of calcium and poor of nitrogen. The content of some microelements as ferrous, manganese and zinc is high.

Analytical data for the content of macro and microelements in the treated water, which participated in the experiments carried out, as well as their content in the soil, are shown in Table 5.

5. Characteristics of the soil and the treated wastewater where vegetation experiments have been carried out

Indicators	Treated water (daily average)	Soil	Indicators	Treated water (daily average)	Soil
Total N, %	0.0163	0.147	*Mn, mg/kg*	0.160	1052.82
Total P_2O_5,%	0.0019	0.210	*Co, mg/kg*	0.006	0.00
Total K_2O,%	0.0007	0.498	*Cd, mg/kg*	0.002	0.00
Na, %	---	0.068	*Ni, mg/kg*	0.015	0.00
Ca, %	---	0.692	*Pb, mg/kg*	0.018	0.00
Zn, mg/kg	0.180	113.24	*NH_4^+-N,%*	0.008	---
Cu, mg/kg	0.030	86.43	*pH*	7.92	7.66

All vegetation experiments have been carried out following the same scheme, i.e. in 3 kg vessels, 4repetitions. It is important to know that generous water quantity has been used for irrigation because the temperature was high, the evaporation has been very intensive and it required daily irrigation. These are not natural conditions for agriculture production and they could lead to significant changes for short period.

During the vegetation period, biometrical measurements have been carried out to monitor plant development. The yield harvest has been recorded and average plant samples have been taken for determination of the content of macro- and microelements, and heavy metals.

Results and discussion. Assessment of the treated wastewater for irrigation depending on the availability of heavy metals

The geochemical fact of availability of heavy metals in the soil and natural water treats them as microelements, i.e. compound elements of the soil and impurity to the water as a micro concentration: mg per kg soil and µg per liter water. Considering it as a natural background most of them as copper, manganese, zinc, cobalt, selenium, molybdenum, nickel, etc., are considered as significantly useful for organism world (plants, animals, human beings). If the concentration is bigger, they are toxic and from indispensable, they become risky factors. Other elements as lead, cadmium, mercury, arsenic, etc. are not indispensable for the organisms unless it is necessary for a specific biological group. They have significant toxic effect and require special attention. The mercury, lead and cadmium have priority at the environment pollution for their accumulation in biological organisms with increasing concentration rate in the water-soil-plant-animal-human being chain.

Main source of heavy metals for the human beings is from the food. Therefore, the agriculture as a big water consumer has specific requirements towards the water quality in relation to the heavy metals.

The high techno-gene saturation of the Sofia Valley is the reason for dispersion of some aerosols and heavy metals dust. Plant growing in this area traditionally is directed for the satisfaction of animal husbandry with fodders and in the same time has significant contribution for vegetable supply of the capital. However, these crops require the biggest quantity water for irrigation and in the same time, they are most pliable to pollution and toxic heavy metal carriage towards human beings and animals. It is obvious that the consequences from the industrial activity in the valley will increase if the soil will be additionally burdened with heavy metals from water with concentration above permissible values.

Those norms are regulated in the irrigation water requirements, and the values in mg/l are, as follows:

Cadmium	Lead	Chromium	Manganese	Arsenic	Nickel	Iron	Cuprum	Zink
0.01	0.1	0.1	0.8	0.5	1.0	1.5	3.0	10.0

It is expected that those values are derivatives of the toxic equivalents of the relative elements and comparing each other raises a lot of questions. There are no soil-chemical reasons, which are based on various interactions with soil and related norms based on the heavy metals different assimilation from plants. These interpretations of the existing standard for water of category 3 justify the task approach.

Analysis of the twenty-four-hour (hourly) samples. Tables 1, 2 and 3 show the heavy metal content at samples taken during entire day. It could be seen that the measured concentrations of all elements except cadmium vary below the limited permissible concentration. Considering the due upper limit there are two groups.

- below the maximum permissible concentration: zinc, nickel, manganese, chrome and cobalt;

- above the maximum permissible concentration: copper, lead, arsenic and cadmium.

The dynamic is seen in the next decreasing string:

Manganese ≥ Nickel > Zinc ≥ Lead ≥ Cobalt = Chrome = Copper > Cadmium > Arsenic.

To sum up, the conclusion is that the elements above the maximum permissible concentration show relatively constant structure of the water.

Research of daily samples at one-month monitoring. Table 4 illustrates the chemical characteristic of the treated water by days. Generally, daily samples have higher concentrations comparing to the twenty-four-hour samples (zinc, copper, lead, cobalt, manganese and arsenic). The measured concentrations of all elements are below the level of the maximum permissible concentration while the likelihood limits increase above this level at lead, cadmium, chrome and mercury. The discrepancy between the measured and the predicted values is a criterion for significant water dynamic in view of the most important toxic elements. Unsatisfying for the monitoring process is also the fact that daily samples outline increasing function sat four elements (arsenic, cadmium, lead and mercury). This characteristic of the dynamic, especially for mercury and arsenic, reflects to the statistic interval below and above the maximum permissible concentration of these elements.

Assessment of the annual dose of heavy metals in the soil originated by the irrigation and the years necessary for its accumulation up to the maximum permissible concentration for soils. Table 6 shows the statistically average background contents of heavy metals in soils which are in the south of Lesnovska River.

6. Calculated terms (years) for attaining the level of the maximum permissible concentration for the heavy metals in soils related to the annual input, output by the plants and accumulation in the soil (mg/kg) at the average irrigation norm(4,000 $m^3.ha^{-1}$) for the crops in the region (maximum average experiment data)

Elements	Maximum permissible concentration	Background	Maximum Permissible concentration-background	Input	Output	Accumulation	Years
Zn	340	103	234	0.270	0.100	0.170	1376
Cu	270	56	214	0.100	0.030	0.070	3057
Pb	80	38	42	0.060	0.015	0.045	933
Cd	3	0.7	2.3	0.030	0.002	0.028	82
Ni	70	26	44	0.120	0.007	0.113	389
Co	---	18	---	0.060	0.001	0.059	---
Cr	200	55	145	0.060	0.002	0.058	2500
Mn	---	900	---	0.220	0.0115	0.085	---
As	25	14	11	0.100	0.010	0.090	122
Hg	1	0.05	0.95	0.020	0.003	0.017	56

The maximum permissible concentration for heavy metals corresponds to the optimum soil acidity, announced by the Bulgarian Governmental Regulations.

The analysis of the research results shows that the treated wastewater is suitable for irrigation considering the heavy metals. In view of the soil constant pollution from the air it is recommendable to confine the usage mainly to the fields allocated in the south of Lesnovska River and in the west of Sofia. The heavy metal availability should be monitored and controlled periodically. The analysis of the treated water originated from the SCWWTS should continue.

Conclusions. 1. The characteristics of the treated wastewater show that it is suitable for irrigation concerning its nourishing elements and heavy metals because they satisfy the requirements for irrigation water;

2. The vegetation experiments carried out show that the treated wastewater could be used for irrigation concerning the content of heavy metals and nourishing elements. The experiments with sludge and treated wastewater have to be carried out for longer period aiming to assess the accumulating impact on soil and plants at field conditions.

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