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MICROBIOLOGICAL ASSESSMENT OF DRINKING WATER QUALITY AT DIFFERENT STAGES OF WATER TREATMENT

Об'єктом дослідження є якість джерел централізованого водопостачання за епідеміологічними показниками та технологія їх знезараження на різних стадіях водопідготовки на прикладі комунального підприємства (КП) «Житомирводоканал» (Україна). У роботі здійснено оцінку об'єкта дослідження та встановлено, що вивчення бактеріологічного стану водних об'єктів, що є джерелами централізованого водопостачання, наразі є одним з найважливіших завдань. Особливо з огляду на значний вплив господарської діяльності людини на поверхневі води та недостатні темпи модернізації обладнання для водопідготовки. Визначено, що широко поширені методи дезінфекції з використанням ультрафіолету та хімічних речовин (хлорування та озонування) мають свої сильні сторони та недоліки. У роботі наведено результати аналізів води з джерел централізованого водопостачання на різних стадіях водопідготовки за мікробіологічними показникам протягом 2019 року: загальне мікробне число (ЗМЧ) та загальна кількість коліфагів. Встановлено незадовільний стан водойм, що є джерелом водопостачання у місті. Доведено, що існуюча технологія знезараження води з джерел централізованого водопостачання, яка здійснюється у два етапи з використанням розчинного хлору та гіпохлориту натрію, є ефективною у знешкодженні бактерій групи кишкової палички. У результаті досліджень виявлено залежність концентрації мікроорганізмів у водних джерелах централізованого водопостачання від погодних умов (найбільше мікробне забруднення спостерігається з травня по жовтень місяць). Доведено помірний рівень забруднення води (в межах від 1,1 од. до 7,5 од.) за епідеміологічним критерієм у водосховищах «Дениші» та «Відсічне» (Житомирська область, Україна). Встановлено, що у резервуарах чистої води епідеміологічний критерій має допустимий рівень. Можна стверджувати, що вода у резервуарах є придатною для питного водокористування місцевим населенням. Таким чином, результати дослідження доводять, що технологія знезараження води (передбачає запровадження двох стадій обробки води), що використовується на КП «Житомирводоканал», є ефективною. Відповідно, ця технологія може бути цікавою і для інших населених пунктів, при відсутності значних коштів на модернізацію обладнання та в умовах змін клімату, що супроводжується щорічним підвищенням температури та зростанням кількості мікроорганізмів у водних джерелах.

Ключові слова: *мікробіологічне забруднення, питна вода, водопідготовка, епідеміологічний показник, моніторинг якості води, сезонні зміни.*

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1. Introduction

Providing the population with fresh water is one of the most important socio-environmental tasks both in Ukraine and abroad. Every year there is an acute problem of deterioration in the quality of drinking water. Indeed, the use of drinking water of unsatisfactory quality can lead to the emergence of many diseases, including infectious ones.

The main sources of centralized water supply are surface waters, which are constantly exposed to significant anthropogenic pollution. They are also affected by climatic conditions, which can both reduce the anthropogenic impact on water sources and increase it. In particular, with an increase in average daily temperature, the growth of microorganisms in water bodies, including pathogenic ones, increases. This leads to an increase in the load on the disinfection process during water treatment. Therefore, research on the quality of surface sources of centralized water supply is relevant, which leads to a solution to the problem of effective disinfection of water at the stages of drinking water treatment for the population.

2. The object of research and its technological audit

The object of research is the quality of sources of centralized water supply according to epidemiological indications and the technology of their disinfection at different stages of water treatment using the example of the utility company (UC) «Zhytomyrvodokanal» (Ukraine).

To provide drinking water to the population of the city of Zhytomyr, water is taken from the «Vidsichne» reservoir on the Teteriv River, which is a source of centralized water supply. To control the water level in it, the

«Denyshi» reservoir is used, which is also used to accumulate water supplies for the needs of the city. For the purpose of proper purification and preparation of drinking water at the water utility, two stages of its disinfection are used:

1. On the first ascent, water from the «Denyshi» reservoir is disinfected with chlorine and enters the «Vidsichne» reservoir. Preliminary water treatment begins already at the site of the first lift and consists of water intake structures: a receiving head with fish protection equipment, water reception lines, a coastal water reception well with nets. The machine room delivers water to high-speed filters, where the cleaning passes through a 50 micron mesh bag. Further, the water is chlorinated and through the raw water pipelines d=1200 mm and d=600 mm enters the treatment plant of the second rise.

2. On the second rise, the water from the Vidsichne reservoir is disinfected with sodium hypochlorite and fed to clean water tanks, from which it is transported through the city's distribution water system using the third and fourth rise to the population.

Water quality is constantly monitored at all stages of water treatment, including treatment – «Denyshi» reservoir, «Vidsichne» reservoir and clean water tanks. For cleaning, reagents are used, the concentration of which depends on the quality of water in the «Vidsichne» reservoir. However, the quality of this water varies with the season, weather conditions and its temperature.

The epidemiological safety of water sources at different stages of water treatment is monitored by the following indicators: total microbial number; total number of coliphages. Coliforms (class of gram-negative rods) include *E. coli, Citrobacter, Enterobacter, Klebsiella, Enterobacter-cloasae, Citrobacterfreundii*. The level of water pollution by pathogenic microorganisms is determined by the presence of *E. coli* in it. Coliforms usually do not cause serious diseases, but they are used as sanitary-indicative (marker) microorganisms, a large number of which indicates the presence of more pathogenic bacteria and viruses [1, 2].

The total microbial number is an indicator of the total bacteriological pollution of water, the sharp increase of which characterizes the occurrence of a source of pollution, including factors of secondary reproduction of microflora [3].

Thus, the study of the bacteriological state of water bodies that are sources of centralized water supply is currently one of the most important tasks of modern hydroecological research, especially given the significant impact of human activities on surface waters.

3. The aim and objectives of research

The aim of research is assessing the quality of water from sources of centralized water supply according to microbiological indicators.

To achieve the aim, the following objectives are set:

1. To analyze the technology of disinfecting water from sources of centralized water supply at various stages of preparation for example «Zhytomyrvodokanal» UC.

2. To conduct research on the quality of water from sources of centralized water supply according to microbiological indicators and investigate seasonal changes.

3. To assess water quality by epidemiological indicator at different times of the year.

4. Research of existing solutions of the problem

Drinking water pollution is a dominant environmental problem in most countries of the world. One of the key aspects of its solution is the introduction of water purification systems from pathogenic microorganisms. Water disinfection technologies in the course of its water treatment involve the use of physical and chemical disinfection methods. For example, in the recommendations on the organization of the water purification process developed by the Environmental Protection Agency, it is noted that it is advisable to use disinfection methods using ultraviolet radiation and chemicals (chlorination and ozonation). Moreover, in the recommendations it is noted that each of the above methods has both positive aspects, provides a sufficient degree of its effectiveness, as well as disadvantages, do not allow to choose one of them as universal [4].

It is proved that the physical method of water disinfection with ultraviolet (UV) is an environmentally safe and quite effective method of killing bacteria, viruses and protozoa [5, 6]. Ozonation is also used, which is considered quite effective in the destruction of viruses and bacteria. In addition, ozone quickly turns into oxygen and does not harm living organisms and people. However, this method is not economic and requires significant costs for energy resources [4].

The most widespread method of water purification is the use of chlorine (chlorine dioxin, sodium hypochlorite, chloramine) as a chemical disinfectant. Residues of free chlorine, namely hypochlorous acid, hypochlorite ion, and elemental chlorine, are most often used to disinfect water [7, 8]. However, this method is quite dangerous for living organisms and potentially dangerous for the person itself, so it is necessary to carefully monitor the concentration of disinfectants, add to water. Another disinfectant that can be added to water is sodium hypochlorite. The use of solutions of such substances is effective for combating viruses, bacteria and fungi in water [9, 10].

So, high microbiological contamination of water requires effective disinfection, for this they use various chemicals, in particular those based on chlorine. And such technologies are quite justified because they are able to provide water purification from pathogenic microorganisms that can cause numerous diseases of people [11]. On the other hand, these technologies affect the organoleptic qualities of drinking water, cause a negative reaction in the population [12], so it is worthwhile to focus on the study of alternative technologies for water disinfection.

Since the water channels use the chlorination method at certain stages of water treatment to neutralize pathogenic microorganisms in water, an important question arises of studying the effectiveness of its use, especially in the face of climate change and seasonal increase in the degree of microbiological pollution.

5. Methods of research

The study of microbiological and chemical indicators of the selected objects was carried out in accordance with the methods approved by the Ministry of Health and current DSTU. According to standard methods, water samples were taken from sources of centralized water supply.

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The determination of microbiological indicators in water was carried out in accordance with the guidelines «Sanitary and microbiological quality control of drinking water», approved by order of the Ministry of Health of Ukraine No. 60 of February 3, 2005.

The determination of the total microbial number was carried out by the method of deep seeding of water in nutrient agar. The calculation of the colony is carried out at 2–5-fold increased, grown at a temperature of 36 °C for 24 hours.

The determination of coliform bacteria is carried out by membrane filtration. The essence of this method is to filter 1 liter of water through special filters and incubate them in Endo medium at a temperature of 36 °C. Subsequently, grown colonies are calculated and identified.

To conduct a comprehensive assessment of water quality, the epidemiological (microbial contamination) criterion was used. Since some indicators can relate to several groups of harmfulness, in a comprehensive assessment, the calculation was carried out for each limiting sign separately according to the formula:

$$W = 1 + \frac{\sum_{i=1}^{n}(\delta_i - 1)}{n}; \quad \delta_i = \frac{c_i}{N_i},$$

where W – comprehensive assessment of the degree of water pollution by a certain limiting sign of harmfulness; n – the number of indicators used in the calculation; N_i – the value of the norm of a separate indicator (mainly $N_i = MPC_i$); δ_i ratio of the excess of the actual concentration of the i-th ingredient in water (c_i) to the value of the standard for an individual indicator.

If $\delta_i < 1$, that is, the concentration is less than the standard, then $\delta_i = 1$.

The pollution level according to the epidemiological criterion was determined in accordance with the tabulated ranges of the values of the integrated estimates W [13]: the permissible level is 1; moderate – 1.0–10.0; high – 10.0–100.0: very high – >100.0.

6. Research results

The analysis of water from sources of centralized water supply at different stages of water treatment according to microbiological indicators during 2019 was carried out: total microbial number (TMN) and total number of coliphages. The water intake for the study was carried out from the «Denyshi», «Vidsichne» reservoirs and two clean water tanks (CWT-1, CWT-2). The results of a study of seasonal changes in water quality from reservoirs are shown in Fig. 1, 2.

A significant increase in TMN in water from the «Denyshi» reservoir was observed in June (463 CFU/cm^3) and in September (206 CFU/cm^3), which is associated with secondary water pollution and weather conditions. A slight increase in September was detected in the Vidsichne reservoir, although during the entire period it did not exceed the normative value.

Unlike the total microbial number, the bacteria of the Escherichia coli group in the water from the «Denyshi» reservoir significantly exceed the standard values from May (2.5 times) to October (2.9 times) a month, which corresponds to the unsatisfactory ecological state of the reservoir. A significant growth of microorganisms is observed during the summer months – in the range from 13.7 to 28.1 times the excess of the standard value. First of all, this is due to an increase in water temperature and lack of precipitation this year. The most critical months are June and September.

The average values of seasonal changes in water quality according to microbiological indicators are given in Table 1.

It is found that during disinfection of water from the «Denyshi» reservoir, the number of microorganisms is significantly reduced, and in some cases even lower than the standard value. However, the number of total coliphages in the water from the «Vidsichne» reservoir in the summer and autumn is quite high and exceeds the standard value by more than 7 times.

Disinfection of water from the Vidsichne reservoir is carried out using sodium hypochlorite, it is quite effective, since in two tanks of clean water there are no bacteria of the Escherichia coli group during the entire study period. Thus, the research results prove the need for disinfection of water in two stages.

A comprehensive assessment of the degree of water pollution by microbiological indicators related to the epidemiological criterion is carried out (Table 2).

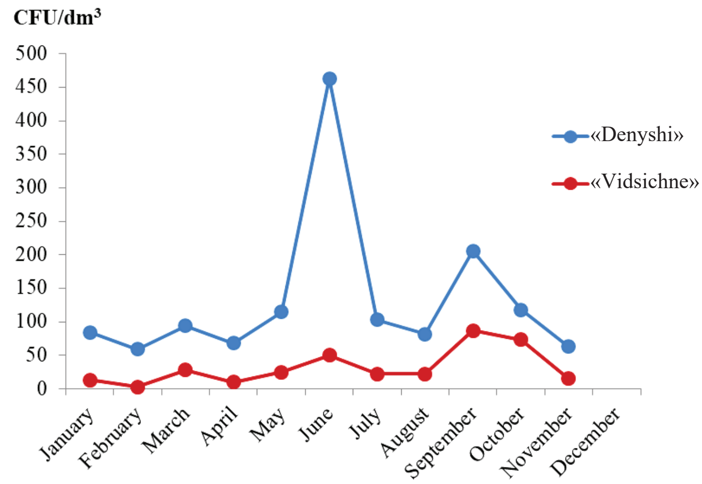

Fig. 1. The value of the total microbial number in water sources of centralized water supply

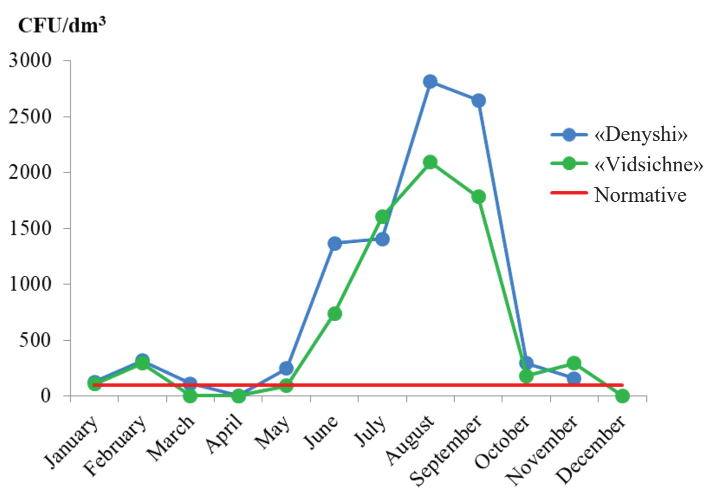

Fig. 2. The importance of total coliforms in water sources of centralized water supply

Table 1

Monitoring seasonal changes in water quality from sources of centralized water supply according to microbiological indicators

No.	Object	Seasons			
		winter	spring	summer	autumn
Total microbial number					
1	Denyshi reservoir	72	92	216	129
2	Vidsichne reservoir	8	21	31	58
3	CWT-1/CWT-2	5/5	3/3	4/3	5/3
Total coliphages					
4	Denyshi reservoir	221	150	1861	1032
5	Vidsichne reservoir	201	90	1477	751
6	CWT-1/CWT-2	0/0	0/0	0/0	0/0

Table 2

The degree of water pollution from sources of centralized water supply according to epidemiological criteria

No.	Object	Seasons			
		winter	spring	summer	autumn
1	Denyshi reservoir	1.5	1.2	10.4	5.8
2	Vidsichne reservoir	1.1	<1	7.5	4.1
3	CWT-1	<1	<1	<1	<1
4	CWT-2	<1	<1	<1	<1

In winter and spring, the water from the «Denyshi» reservoir has a moderate degree of pollution and amounts to 1.5 units and 1.2 units, respectively. In the summer, this indicator significantly increases to 10.4 units. Therefore, water has a high degree of pollution, making it impossible to use it for drinking water supply. It is in the summer that the issue of water disinfection at the stages of water treatment is particularly acute, since there is an intensive growth of microorganisms, including pathogenic ones. Water also has a moderate degree of pollution in the autumn period (5.8 units), however, it is almost 5 times higher than in spring.

The water from the «Vidsichne» reservoir has a moderate degree of pollution during the year and ranges from 1.1 units up to 7.5 units, which is a danger to the population and requires special water treatment measures. An exception is the spring period, since water has an acceptable level of pollution.

It is established that the water from the clean water tanks during the entire period of the study has an acceptable degree of pollution, and, therefore, is suitable for drinking water use by the local population. Thus, the technology for disinfecting the water used on the water utility is effective.

7. SWOT analysis of research results

Strengths. The technology of water disinfection used at «Zhytomyrvodokanal» UC is effective. Considering the available equipment, the condition of open water sources and the volumes of water to be treated, the two-stage system provides the best result at the optimal cost. Accordingly, this technology may be interesting for other settlements, in the absence of significant funds for the modernization of equipment and in the face of climate change, accompanied by an annual increase in temperature and an increase in the number of microorganisms in water sources.

Weaknesses. As a reagent, providing disinfection of water from pathogenic microorganisms, chemical reagents based on chlorine are used. However, such substances affect the organoleptic indicators of water quality and are potentially dangerous for living organisms and people. In addition, the condition of the water supply network in the city is unsatisfactory. This creates the likelihood of secondary microbiological contamination of water.

Opportunities. Prior to the introduction of ultraviolet (UV) water disinfection technology, the «Zhytomyrvodokanal» UC is considered as an additional degree of water purification. The technology is considered effective for disinfection and environmentally friendly. However, such a technology is complicated from the point of view of its implementation and is not economical enough.

Threats. Climatic changes affect the increase in average daily temperature, a decrease in precipitation, which can lead to an increase in the degree of microbial contamination. In this case, it will be necessary to use high doses of chlorine-based chemicals for disinfection, which will also affect the quality of drinking water. The use of other disinfection methods will require additional financial costs for their implementation.

8. Conclusions

1. The existing technology for disinfecting water from sources of centralized water supply, which is carried out in two stages using soluble chlorine and sodium hypochlorite, is analyzed. Its effectiveness in neutralizing a high amount of *E. coli* bacteria is proven.

2. It is proved that the concentration of microorganisms in the water sources of centralized water supply significantly depends on weather conditions. Most of all, microbial pollution is observed from May to October in the reservoirs, in particular during the summer months there is an excess of the standard value of coliforms by more than 20 times.

3. It is established that the water in the «Denyshi» and «Vidsychne» reservoirs, according to epidemiological criteria, should have a moderate level of pollution and range from 1.1 units up to 7.5 units, while in clean water tanks it has an acceptable level of pollution throughout the entire period of the study.

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