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HYGIENIC ASSESSMENT OF POTENTIAL HEALTH RISKS FOR THE POPULATION OF UKRAINE AND THE KHARKIV REGION AS A RESULT OF THE DETERIORATION OF DRINKING WATER SUPPLY IN THE CONDITIONS OF WAR

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Water plays a key role in ensuring the social and ecological well-being of the population of any state. At the same time, fresh water as a resource and related water infrastructure are among the most vulnerable sectors during armed conflicts. In this regard, it is relevant to study the impact of the armed conflict on water supply and the water system of Ukraine.

The aim of the study *was to analyze the impact of military actions on the state of drinking water supply in Ukraine and the Kharkiv region and its potential impact on the state of health of the local population.*

Materials and methods. *Weekly reports of the Ministry of Ecology and Natural Resources of Ukraine, reports of the Ministry of Reintegration of Temporarily Occupied Territories and Internally Displaced Persons of Ukraine, reports of Ukrainian regional military administrations, and a report of the Kharkiv Laboratory Center on the analysis of the state of drinking water supply in the settlements of the Kharkiv region and the city were used as the main source of information.*

Results. *As a result of the conducted analytical research, various types of influence of military operations on the water supply system of Ukraine were revealed. An increase in the level of surface water pollution has been established, in particular due to sunken military facilities and emissions of chemical substances as a result of shelling. Several impacts have been identified as potential threats, including flooding due to damage to dams, threats related to nuclear power plants, incidents of periodic flooding of underground mines, possible detonation of chlorine tanks in the area of wastewater treatment plants, and sea mine explosions in the Danube Delta. The results of the conducted research revealed that the quality of drinking water in the water supply systems of some settlements of Ukraine does not meet the hygienic requirements in terms of bacteriological, sanitary-chemical and radiation indicators. High concentrations of metals and their compounds entering the tissues of the body in the form of an aqueous solution pose a particular danger to the health of the population*

Conclusion. *As a result of Russia's armed aggression, wastewater treatment systems were disrupted, which led to an increase in the pollution of surface water sources*

Keywords: *military aggression, drinking water supply, endemic diseases, water infrastructure, nitrates, methemoglobinemia, salts of heavy metals*

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1. Introduction

Russia's armed aggression in Ukraine, which began on February 24, 2022, is an exceptional case from the point of view of its impact on the environment in general and on water resources and water infrastructure of Ukraine in particular. After all, the territory of our state is characterized by a modified and industrialized water sector (Fig. 1) [1, 2].

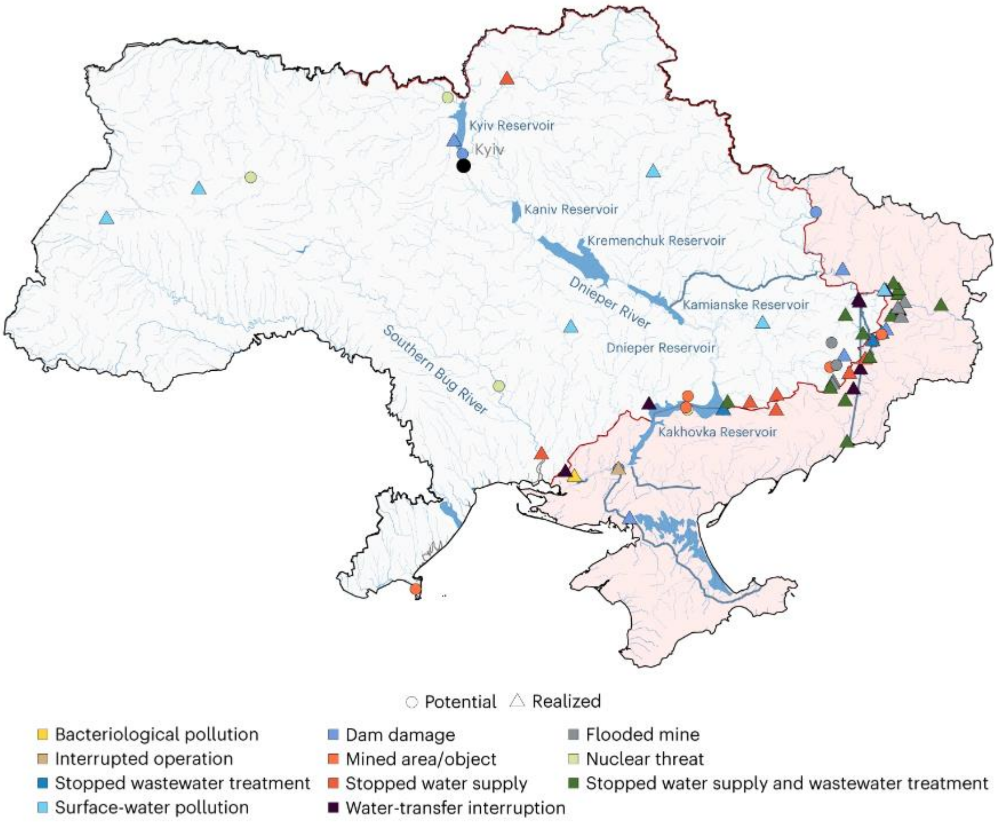

Fig. 1. Location of the main river basins of Ukraine

Ukraine's global water infrastructure includes large multi-purpose reservoirs, cooling facilities for nuclear power plants, reservoirs used for industry and mining, as well as large water distribution channels and pipelines for irrigation and household purposes [3–6]. Most of this water infrastructure is located in the eastern and southern parts of the country, in areas of intensive agricultural production and large industrial activities such as metallurgy, coal mining and chemical production. The war in Ukraine has a colossal impact on freshwater resources and water infrastructure, both on the livelihoods of the local population and on the global food supply, reflecting the importance of water resources for our country's agriculture [7, 8].

High concentrations of metals and their compounds entering the tissues of the body in the form of an aqueous solution pose a particular danger to the health of the population. At the same time, all internal organs are affected. Their removal from the body through the intestines, lungs and kidneys leads to disruption of the activity of these organs [3, 9]. No less dangerous is the chronic entry of these compounds into the body, because their accumulation leads to damage to the kidneys (mercury, lead, copper), damage to the liver (zinc, cobalt, nickel), damage to capillaries (arsenic, bismuth, iron, manganese); damage to the heart muscle (copper, lead, zinc, cadmium, mercury, thallium), the occurrence of oncological diseases (cadmium, cobalt, nickel, arsenic, radioactive isotopes) [10, 11].

According to the State Environmental Inspection of Ukraine, during the period of full-scale aggression, Russia caused significant man-made pollution due to the clogging of waters and arbitrary use of water resources. Especially in the most vulnerable regions, in particular in the Kharkiv region [12–14].

That is why **the aim of our study** was to analyze the impact of military operations on the state of drinking water supply in Ukraine and the Kharkiv region and its potential impact on the health of the local population.

2. Materials and methods

Information on the impact of armed conflict on water resources and infrastructure was collected between February and September 2022, covering the first eight months of the armed conflict. As the main source of information, we used the weekly reports of the Ministry of Ecology and Natural Resources of Ukraine, reports of the Ministry of Reintegration of Temporarily Occupied Territories and Internally Displaced Persons of Ukraine, reports of Ukrainian regional military administrations, and the report of the Kharkiv Laboratory Center on the analysis of the state of drinking water supply in the settlements of the Kharkiv region and of the city of Kharkiv [13–16]. To search for information from mass media, we used Google search keywords related to the declared consequences in Ukrainian, Russian and English languages.

3. Research results

As a result of the conducted analytical study, the following types of impact on the water supply system of Ukraine were revealed: in the southern region, eight cases of water supply interruption, six cases of surface water pollution due to military operations, in particular due to sunken military facilities and emissions of chemical substances due to shelling, were recorded in the southern region [17–19]. Five cases of damage to dams (four on reservoirs and one along the North Crimean Canal), six cases of mine flooding, a global case of bacteriological pollution due to the mass death of domestic animals and fish due to the explosion of the hydroelectric power plant (Kakhovskaya HPP) were established [20–22].

In addition, a strong impact on the water supply and wastewater treatment systems was revealed, including 12 cases of disruption of water supply and treatment facilities, seven cases of disruption of centralized water supply and three cases of disruption of water treatment facilities [23, 24].

Out of the analyzed impacts, 17 are the result of direct attacks, 13 are due to power outages, 8 are a combination of both, 4 cases of surface water pollution from sunken military facilities, 1 case related to indirect damage to the water supply system (corrosion and damage to pipes due to connection to alternative source of water supply in the city of Mykolaiv) and 1 due to non-standard operating conditions (flooding in Novaya Kakhovka). As for the water supply infrastructure, as a result of the hostilities, 12 pumping stations were damaged, pipelines and dams were damaged in 6 cases, treatment facilities were damaged in 3 cases, 2 filter stations with water intake facilities and 1 artesian well were damaged. In total, in 12 settlements, such damage led to the complete failure of the entire water supply and wastewater treatment system [25, 26].

A number of impacts were identified as potential threats, including flooding due to damage to dams (for example, potential missile strikes on the dam of the Kyiv HPP, explosion of the road on the dam of the Pecheneg reservoir, 5 reservoirs mined), threats related to the NPP due to the low trajectory of the missiles (possible damage to cooling reservoirs, spread of radioactive dust), cases of periodic flooding of underground mines, possible detonation of a container with chlorine in the territory of wastewater treatment facilities and explosions of sea mines in the Danube delta [27, 28].

Fresh water resources and water infrastructure were affected primarily in Donetsk, Luhansk and Kharkiv regions, where the conflict was most intense. The maximum number of incidents was registered in the basin of the Siverskyi Donets River. The lack of electricity supply in the region led to the interruption of remote areas (the main source of water supply) and caused an uncontrolled rise of contaminated mine waters [29].

Several cases of impact on freshwater resources and water infrastructure were also recorded in the western regions of Ukraine, far from active ground military operations. For example, the attack on an oil depot in Lviv led to the pollution of the Western Bug River, a tributary of the Narva River (Vistula River basin) [8]. In the north of the Ternopil region, as a result of shelling, six reservoirs with mineral fertilizers were damaged, which led to the pollution of the Ikva River, a tributary of the Styr River (Dnieper basin). This led to significant increases in ammonia and nitrate concentrations and mass fish kills. In the Odesa region in southern Ukraine, local authorities reported the presence of sea mines in the Danube River Delta, which also poses a number of potential man-made pollution threats.

In January-June 2022, the Kharkiv Laboratory Center (KLC) conducted a large-scale study of sources of centralized water supply [30]. In Kharkiv region, ecologists took 2,542 samples. 25 % of the tests showed that the water is not suitable for human consumption. In some areas of the region, there is almost no drinking water in the central pipeline.

The largest percentage of samples with deviations from normative indicators was registered in:

– Lozivskyi (82.9 %),
– Dvorichanskyi (60.7 %),
– Blyzniukivskyi (56.5 %),
– Zolochivskyi (51.3 %),
– Pervomaiskyi (42.5 %),
– Sakhnovshchynskyi (41.6 %),
– Vovchanskyi (32.5 %) district.

The situation is even worse with non-centralized sources of water supply. According to the statistics of the KLC, the water in every second well in the Kharkiv region does not meet sanitary requirements. Exceeding indicators of total hardness, turbidity, content of nitrates, ammonia, sulfates, chlorides, dry residue and iron were found in the tested samples.

In 2022, specialists of the Laboratory Center examined 131 samples of drinking water from Kharkiv sources: 67 – for sanitary and chemical indicators and 64 – for microbiological ones. Out of them, 29.9 % and 21.9 %, respectively, showed deviations from the norm.

There are a total of 11 springs on the territory of Kharkiv:

Sarzhyn ravine, Otakar Yarosh Street; Oleksiivska balka, Klochkivska Street; Manjosiv ravine; Mineralovodska street, 1; the village of Oleshka; 198 Poltavsky Shlyach Street (Yunist Park); Hlyboki ravine, 25 Zubenka Street; Kytlyarchyn ravine, Buchma street; Petrenki-1; Petrenki-2; Petrenki-3.

According to microbiological parameters, the drinking water taken from the following sources did not meet the requirements: 198 Poltavsky Shlyach Street (Youth Park); Oleksiivska balka, Klochkivska Street; Kytlyarchyn ravine (Buchma Street).

According to sanitary and chemical indicators, deviations from the norm were found in the samples of water taken from the sources: 198 Poltavsky Shlyach Street, Yunist Park (exceeding hardness and nitrate content); Kytlyarchyn ravine (Buchma Street) (increased turbidity and total iron content) 1 Mineralovodska Street (inconsistency in the hydrogen indicator) (Table 1).

Table 1

Indicators of water quality in centralized sources of the city of Kharkiv

Indicators	Standard SSS 2.2.4-171-10	units of measurement	198 Poltavsky Shlyach Street, Yunist Park	Oleksiivska balka, Klochkivska Street	Sarzhyn ravine, Otakar Yarosh Street	Hlyboki ravine, 25 Zubenka Street	1 Mineralovodska Street	Kytlyarchyn ravine, Buchma Street
Microbiological indicators								
Common coliforms	absent	CFU/ 100 ml	absent	**5**	absent	absent	absent	**3**
Total microbial count	<100	CFU/ ml	150	120	0	0	0	120
Escherichia coli	absent	CFU/ 100 ml	absent	absent	absent	absent	absent	absent
Enterococcus	absent	CFU/ ml	absent	absent	absent	absent	absent	absent
Organoleptic indicators								
The smell at t 20 °C	<2	points	1 chalk	1 H_2S	1 крейд	1 H_2S	0	1-2
The smell at t 60 °C	<2	points	1 chalk	1	0	1	0	1-2
Coloration	<20	degrees	7.18	13	2.78	12	1.05	11.04
Flavor	<2	points	1	1	1	1	1	1
Turbidity	<1.5	g/cm^3	1.45	1.25	0.47	1.34	0.02	1.7
Physico-chemical indicators								
pH	6.8–8.5	one pH	7.40	7.17	7.69	7.49	5.9	7.38
General iron	<0.2	mg/dm^3	0.2	0.2	0.12	0.19	0.04	0.425
General stiffness	<7.0	mmol/dm^3	8.9	5.15	2.01	3.8	6.77	2.9
Manganese	<0.05	mg/dm^3	0.04	0.04	0.02	0.04	0.05	0.04
Copper	<1.0	mg/dm^3	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Polyphosphates	<3.5	mg/dm^3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sulfates	<250	mg/dm^3	5.73	7.05	2.6	1.7	1.96	2.34
Dry residue	<1000	mg/dm^3	373	378	321	365	396	326
Chlorides	<250	mg/dm^3	15.5	11.8	21.5	19.5	4.9	12.5
Zinc	<1.0	mg/dm^3	0.025	0.024	0.008	0.005	0.017	0.013
Free residual chlorine	<0.5 with chlorination	mg/dm^3	without chlorination	without chlorination	without chlorination	without chlorination	without chlorination	without chlorination
Oil products	<0.1	mg/dm^3	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Anionic surfactants	<0.5	mg/dm^3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sanitary and toxicological indicators								
Ammonium	<0.5	mg/dm^3	0.32	0.44	0.43	0.37	0.05	0.5
Nitrates	<0.5	mg/dm^3	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Nitrite	<50	mg/dm^3	65.0	<0.001	<0.001	<0.001	0.9	<0.001
Fluorides	0.7–1.2	mg/dm^3	0.45	0.34	0.78	0.57	0.38	0.38

4. Discussion of research results

The results show that the types of infrastructure most affected during the first eight months of the armed conflict were dams and reservoirs, underground mines, urban water supply and sewage treatment systems.

Of particular concern are the large reservoirs along the Dnipro River, which are critical for energy production, cooling nuclear power plants, supporting agriculture, and regulating seasonal flow. In addition, there is a high concentration of settlements along the Dnipro River, and in the event of a dam breach, flooding is an immediate threat. In addition to flooding, the breach of dams along the Dnipro River creates a danger of secondary radioactive pollution due to the uncontrolled release of radioactive materials accumulated in sediments and associated with colloidal materials in surface waters after the Chernobyl nuclear power plant disaster [31].

After the accident, the reservoirs of the Dnipro Cascade acted as absorbers of radioactive cesium, and a large accumulation of it was recorded in the Kyiv reservoir. As for radioactive strontium, about 43 % of the dissolved form that entered the Dnipro system from 1987 to 1993 reached the Black Sea. The Zaporizhzhia NPP, the largest NPP in Europe, is located on the banks of the Kakhovsky Reservoir, 40 km downstream from the Dniprovska HPP dam. A sudden loss of water needed for the reactor's active cooling system could lead to a scenario like the accident at the Fukushima Daiichi nuclear power plant in Japan in 2011 [32, 33].

The consequences of violation of sanitary standards in the field of drinking water supply in many cases are inadequate quality of drinking water. Bacteria and viruses contained in them can cause dangerous diseases such as typhus and paratyphoid, salmonellosis, bacterial rubella, cholera, viral meningitis and intestinal diseases, etc. Such water can be a source of parasitic infestations. Municipal sewage contains toxic detergents, complex aromatic hydrocarbons, nitrates and nitrites.

Based on the results of scientific research, it was established that the main water pollutants are iron, ammonia, manganese, chlorides and nitrates. The use of modern water disinfection technologies often leads to the formation of compounds extremely harmful to human health (chloroform - $CHCl_3$, dioxin, etc.) [3, 34].

During 2022, territorial centers for disease control and prevention of the Ministry of Health of Ukraine from sources of centralized water supply, including water pipes, examined 95,453 drinking water samples for sanitary and chemical indicators, and 123,023 samples for microbiological ones.

In 2022, the specific gravity of non-standard samples of drinking water from centralized water supply systems according to sanitary and chemical indicators in the Mykolaiv, Luhansk, Zhytomyr, Rivne, and Kyiv regions, and according to microbiological indicators – in the Khmelnytskyi, Rivne, Ivano-Frankivsk, Mykolaiv, Ternopil, and Vinnytsia regions one and a half times or more exceeds the average indicators for countries.

The results of the conducted research revealed that the quality of drinking water in the water supply systems of some settlements of Ukraine does not meet the hygienic requirements in terms of bacteriological, sanitary-chemical and radiation indicators.

One of the reasons for the increase in pollution is the ingress of dirty sewage into the Kakhovka reservoir as a result of the shutdown of sewage treatment facilities near Zaporizhzhia. It is evidenced by the remote sensing images of this region (Fig. 2).

Fig. 2. Satellite image of wastewater discharge into the Kakhovka reservoir

Rivers and networks of irrigation canals, which are natural obstacles to the movement of troops, also became a place for burial of military objects. Underwater decomposition of munitions results in the release of heavy metals and toxic explosive compounds, the effects of which can last for decades. This can be critical in the southern regions of Ukraine, where there is an extensive network of irrigation canals. The low quality of irrigation water affects the yield of agricultural crops and the quality of food production. In the pre-conflict period, concentrations of heavy metals in the waters of the Kakhovsky Canal met water quality standards, but there is concern that the conflict will lead to deterioration of water quality [27].

In June-July 2022, in the area of the surface drinking water intake in the basin of the Siverskyi Donets River, traces of petroleum products were recorded for the first time, as well as excess concentrations of mercury, ammonium nitrogen, nitrites, polyaromatic carbons, heavy metals and the insecticide cypermethrin in some rivers of the basin.

The threatening scale of potential pollution is also explained by the territorial extent of the Siverskyi Donets river basin. Being the largest river in eastern Ukraine, it has a total length of about 718 km within Ukraine, covers the Kharkiv, Donetsk, and Luhansk regions and extends into the territory of Russia (Fig. 3).

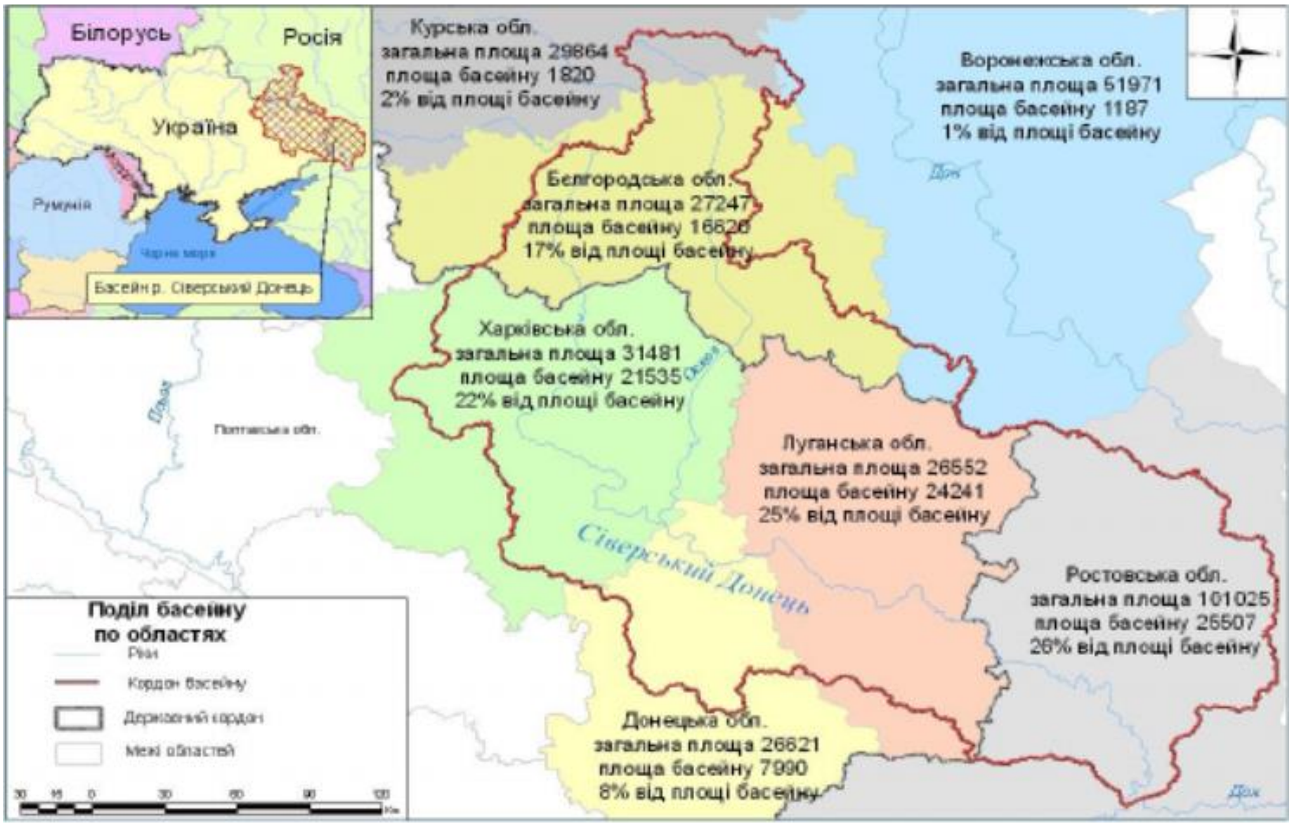

Fig. 3. Division of the Siverskyi Donets river basin by regions

In addition, repeated power outages in Donbass have increased the threat of contamination of water sources with mine waters due to malfunctions of pumping equipment. Flooding of geologically related mines, a long-standing problem in the region, increases mine water salt concentrations to 20–70 % (excluding chlorides) and can double organic and hydrocarbon concentrations. High concentrations of sulfates, chlorides, and heavy metals in mine waters pose serious risks to the quality of groundwater and surface water (for example, the Komyshuvaha River has been heavily polluted by mine waters since 2018).

During the armed conflict, the water supply infrastructure was repeatedly attacked with limited time and little opportunity for repair and restoration. As of April 20, 2022, the United Nations reported that 6 million people in Ukraine struggle daily to access drinking water, with 1.4 million people lacking access to safe water in the east of the country and another 4.6 million people have limited access only. Between March and December 2022, according to UN estimates, about 16 million people in Ukraine will need help with water, sanitation and hygiene. In the city of Mariupol, more than 40 % of the water supply system was reportedly damaged, and on 17 May 2022, the World Health Organization expressed concern about the risk of a cholera epidemic in the city due to the mixing of sewage and drinking water. In Mykolaiv, the population was left without a centralized water supply for more than a month, and the water that was supplied intermittently from an alternative source later had an excessive content of chlorides, sulfates and other mineral salts even after treatment. The population of Donetsk reportedly only receives water for two hours every 3–4 days, and all specialists capable of solving problems with the water supply system have been mobilized during the armed conflict, limiting the ability to repair the system. Luhansk Oblast, with a population of 2.1 million people, was completely without water supply at the beginning of May, and water supply was only possible externally through humanitarian organizations. The lack of access to clean water creates a serious threat of epidemic outbreaks, which has been exacerbated both by the extremely high temperatures observed in the summer of 2022 and by the reduced capacity of the medical system. According to UNICEF, children living in protracted conflict are more likely to die from waterborne diseases than from the military conflict itself.

Expert assessment of the reported and projected effects of armed conflict is in many cases limited by the lack of safe access to affected sites and possible biases and discrepancies in reporting. However, to some extent, the effects of using or targeting water systems during conflict can be assessed based on retrospective analysis of similar impacts on freshwater resources and infrastructure. For example, the catastrophic floods resulting from damage to the Dnipro Hydroelectric Power Plant during World War II and the release of radionuclides through water from the Chernobyl disaster indicate the spatial extent of potential impacts in cases where large reservoirs or nuclear power plants are affected by war. The long-term consequences of environmental pollution due to the impact on water infrastructure were highlighted by the accident related to the spill of potash into the Dniester River due to the flooding of the Stebnytsky landfill in Lviv region in 1983. In this event, more than 3.8 km^3 of highly concentrated spent salts were spilled, which increased the salinity of the Dniester River to levels higher than in seawater. This event led to the disruption of water supply to millions of people in Odesa, Chisinau and Tiraspol region, led to the death of hundreds of tons of fish and severe pollution of the bottom sediments of the river.

Although modern military technology allows for the precise destruction of localized facilities, damage to industrial facilities is not always ecologically localized, and many attacks have been general rather than precise. In highly industrialized Ukraine, targeting urban and industrial infrastructure inevitably leads to large-scale and serious environmental consequences. As of the beginning of June 2022, more than 25 large industrial enterprises of Ukraine were damaged or completely destroyed. The most famous are the ammonia producer AZOT, the coke chemical concern in Avdiivka and the metallurgical center AZOVSTAL in Mariupol. Port infrastructures on the coast of the Black and Azov seas were heavily bombed in Mykolaiv, Odesa and Mariupol. Other impacts on water resources can currently only be estimated, including threats to regional biodiversity.

Therefore, Russia's war against Ukraine has a catastrophic impact on the environment, in particular on water resources and water infrastructure, and carries great risks for the health of the population of our entire state. As a result of the armed conflict, many Ukrainian communities were left without sewage treatment, which led to surface water pollution. But the greatest damage is felt in the territories of active hostilities, occupied and de-occupied territories.

In particular, according to the results of research by the Kharkiv Laboratory Center (KLC), it was established that more than a third of the drinking water of the Kharkiv Region is not suitable for consumption [9].

Nitrate poisoning of children continues to be registered. In 2022, several cases of water-nitrate methemoglobinemia were registered in infants living in the territory of Dergachiv district, Kharkiv city, and Lubotyn city [15].

Almost all drinking water in the Kharkiv region is collected from the rivers of the Siversky Dinets basin. According to experts, the condition of the Uda River is cause for concern. It is the most anthropogenically loaded of all the rivers in the basin. The main source of pollution is the discharge of wastewater into the surface by communal enterprises of the city of Kharkiv. The problem lies in the unsatisfactory state of treatment facilities at these enterprises.

Regional landfills also significantly affect water quality. This is especially relevant for the villages of Dergachi and Ruska Lozova, which are located next to the city landfill. Surface water in these areas is extremely toxic. In eight springs out of 11 studied, the water does not meet the standards.

Study limitations. The limitation of the study is the use of unreliable data and subjective conclusions regarding the results of research and analyzed publications.

Prospects for further research is an assessment of the dynamic state of the environment and the state of water in the conflict zone.

5. Conclusions

As a result of the conducted research, it was established that the military actions led to the deterioration of the quality of drinking water throughout the territory of Ukraine, in particular in the Kharkiv region.

As a result of Russia's armed aggression, wastewater treatment systems were disrupted, which led to an increase in the pollution of surface water sources. Front-line, occupied and de-occupied territories suffered special damage. It was established that more than a third of drinking water sources in the Kharkiv region are unfit for consumption due to exceeding microbiological, physico-chemical and sanitary-toxicological indicators.

Examining the impact of armed conflict on freshwater resources and water infrastructure in Ukraine highlights diverse and long-term consequences for the health of the local population and the state of the region's ecosystems.

Conflict of interests

The authors declare that they have no conflict of interest in relation to this research, including financial, personal, authorship, or any other nature that could affect the research and its results presented in this article.

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Data availability

Data will be provided upon reasonable request.

Use of artificial intelligence technologies

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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