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Peculiarities of the composition of surface and groundwater in eastern Ukraine during the war: assessment of environmental and carcinogenic risks

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Russia’s war against Ukraine has devastating humanitarian, social, economic and environmental consequences. To assess them, it is important to monitor environmental pollutants in the eastern regions of Ukraine. This study analyses the chemical composition of surface and groundwater near the frontline in Zaporizhzhia region and justifies the need to develop a state plan for the restoration of damaged areas.

Aim. To study the content of environmental toxins, organic compounds and heavy metals in surface and ground waters in the south-east of Ukraine near the frontline and to identify areas of high risk of pollution.

Materials and methods. During the period of 2024, 70 drinking water samples were collected and examined from the centralised water supply networks of the city of Zaporizhzhia of the Municipal Enterprise “Vodokanal” and Enterprise of State Criminal-Executive Service of Ukraine. Groundwater samples were taken by professional hydrogeologists on November 9, 2024, near Tarasivka village (geographical coordinates: 47°46′41″N 35°26′36″E / 47.77806°N 35.44333°E) and near Vilne village (geographical coordinates: 47.57286°N 32.61995°E) of Komyshuvakha village, Orikhiv district, Zaporizhzhia region, at a depth of 5, 14 and 190 meters. The water was not preserved and was delivered to the laboratory within a few hours. The chemical analysis was carried out in the laboratory of Ukrkhimanaliz LLC of the Center for Preventive Medicine of the State Administration of Affairs. The presence of heavy metals and organic compounds (50 indicators in total) was studied by atomic emission spectral, photometric, titrimetric, ionometric, colorimetric, chromatographic and calculation methods.

Results. Analysis of 70 samples of drinking water in Zaporizhzhia from the centralised water supply networks of the Municipal Enterprise “Vodokanal” and Enterprise of State Criminal-Executive Service of Ukraine showed that 67–96 % did not meet hygiene standards for trihalogen methanes. Chemical analysis of groundwater showed significant contamination of aquifers at the 5- and 14-meter levels near the frontline due to a significant increase in nitrate and aluminium content. The groundwater was characterized by high levels of salts, sulphates, calcium and magnesium. Such groundwater quality indicators may be related both to the natural features of the area, namely the chemical composition of the soil, and man-made factors caused by the hostilities. The high mineralisation and hardness of the water, and the excessive content of nitrates and heavy metals (aluminium) made the water unsuitable for drinking purposes. At a depth of 190 meters (interstitial water – artesian water), no chemical pollutants were detected, and the organoleptic, sanitary and toxicological indicators met the sanitary and hygienic requirements according to State Sanitary Rules and Norms 2.2.4-171-10 “Hygienic Requirements for Drinking Water Intended for Human Consumption”.

Conclusions. Drinking water from centralised water supply networks in Zaporizhzhia in 67–96 % of cases does not meet hygiene standards for trihalogen methanes. Groundwater in Zaporizhzhia region near the frontline at a depth of 5 and 14 meters is highly mineralised, containing high concentrations of nitrates and aluminium, making it unsuitable for drinking. The artesian water in this region does not contain pollutants of man-made and military origin, which indicates that the interlayer is not damaged, and this water is suitable for drinking. High levels of salt and general hardness of groundwater are associated with the geochemical features of the area. The high nitrate content and 1.4 times higher aluminium levels are the result of soil contamination in the area.

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Особливості складу поверхневих і ґрунтових вод сходу України під час війни: оцінювання екологічних і канцерогенних ризиків

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Війна Росії проти України має руйнівні гуманітарні, соціальні, економічні та екологічні наслідки. Для їх оцінювання важливим є моніторинг забруднювачів довкілля у східних регіонах України. Проаналізували хімічний склад поверхневих і ґрунтових вод біля лінії фронту в Запорізькій області, обґрунтовано необхідність розробки державного плану відновлення пошкоджених територій.

Мета роботи – дослідити вміст екологічних токсинів, органічних сполук і важких металів у поверхневих і ґрунтових водах південного сходу України біля лінії фронту, визначити зони високого ризику забруднення.

Матеріали і методи. Протягом 2024 року з водопровідних мереж централізованого водопостачання м. Запоріжжя КП «Водоканал» і ДП «Підприємство державної кримінально-виконавчої служби України» відібрано та досліджено 70 проб питної води. Відбір 30 проб підземних вод здійснено професійними працівниками-гідрогеологами 09 листопада 2024 року біля села Тарасівка (географічні координати: 47°46′41″ пн. ш. 35°26′36″ сх. д. / 47.77806°пн. ш. 35.44333°сх. д.) та біля села Вільне (географічні координати: 47.57286 пн. ш., 32.61995 сх. д.), селища Комишуваха Оріхівського району Запорізької області на глибині залягання 5 м, 14 м і 190 м (по 10 проб на кожній локації). Воду не консервували і доставляли до лабораторії протягом кількох годин. Хімічний аналіз здійснено в лабораторії ТОВ «Укрхіманаліз» Центру превентивної медицини Державного управління справами. Наявність важких металів і органічних сполук (всього 50 показників) вивчали атомно-емісійним спектральним, фотометричним, титриметричним, іонометричним, колориметричним, хроматографічним і розрахунковим методами.

Результати. Результати аналізу 70 проб питної води м. Запоріжжя з водопровідних мереж централізованого водопостачання КП «Водоканал» і ДП «Підприємство державної кримінально-виконавчої служби України» показали: 67–96 % не відповідали гігієнічним нормативам щодо вмісту тригалогенметанів. Хімічний аналіз підземних вод дав змогу виявити значне забруднення водоносних горизонтів на рівні 5 м і 14 м поблизу лінії фронту внаслідок суттєвого підвищення вмісту нітратів та алюмінію. Ґрунтові води характеризувалися високим вмістом солей, сульфатів, кальцію та магнію. Такі показники якості підземних вод можуть бути пов'язані і з природними особливостями місцевості, а саме хімічним складом ґрунтів, і з техногенними факторами, зумовленими бойовими діями. Висока мінералізація та жорсткість води, перевищений вміст нітратів і важких металів (алюмінію) зробили воду непридатною для споживання. На глибині 190 м (міжпластові води – артезіанська вода) хімічні забруднювачі не виявлено, органолептичні та санітарно-токсикологічні показники відповідали санітарно-гігієнічним вимогам згідно з ДСанПіН 2.2.4-171-10 «Гігієнічні вимоги до питної води, призначеної для споживання людиною».

Висновки. Питна вода з водопровідних мереж централізованого водопостачання в м. Запоріжжя у 67–96 % випадків не відповідає гігієнічним нормативам щодо вмісту тригалогенметанів. Ґрунтові води в Запорізькій області біля лінії фронту на глибині 5 м і 14 м дуже мінералізовані, характеризуються високою концентрацією нітратів і алюмінію, що робить їх непридатними для пиття. Артезіанська вода цього регіону не містить забруднювальних речовин техногенного і воєнного походження, що свідчить про відсутність пошкоджених міжпластових шарів та її придатність для питних потреб. Високі рівні солей і загальна жорсткість у ґрунтових водах пов'язана з геохімічними особливостями місцевості. Високий вміст нітратів і перевищення у 1,4 раза алюмінію є наслідком забруднення ґрунтів у цій місцевості.

Сучасні медичні технології. 2025. Т. 17, № 2(65). С. 83-90

Russia's war against Ukraine has catastrophic destructive humanitarian, social, economic and environmental consequences. The impact of hostilities on the environment and the biosphere is caused by the direct penetration of pollutants into the soil and drinking water in the form of oil products and diesel fuel, heavy metals, toxic compounds, chemical warfare agents and other chemicals [1,2,3].

The intensive use of explosive weapons has damaged coal, oil and gas infrastructure, destroying the environment in some regions. Hydraulic structures have suffered significant damage and destruction. Landscape fires have disrupted ecosystems. Combustion products and chemical pollutants from the air have settled on the ground and appeared in drinking water. The penetration of toxins and carcinogens into deep aquifers was facilitated by soil erosion and degradation along the front lines, which was intensified by shelling and movement of vehicles and heavy machinery [4,5,6].

The marine ecosystems of the Azov and Black Sea basins are also under threat. Due to the spread of toxic substances with groundwater, the high intensity fighting in eastern Ukraine could have significant transboundary effects. Environmental pollution with toxins threatens to spread not only to areas directly affected by the war, but also to other countries [7].

Underground waters near the city of Zaporizhzhia are highly vulnerable. Here, the risk of downward migration of pollutants through the soil and upper rock layers to the aquifer is particularly high.

Monitoring of pollutants in the air, soil and water is important for assessing the short- and long-term environmental impact of the war on the population of Ukraine [8].

Despite the fact that the work of ecologists near the front line is carried out under very difficult circumstances, information on the composition of groundwater and artesian water in the combat zone is extremely important not only for the eastern but also for other regions of Ukraine.

The significant changes in the hydrological regime of the Dnipro reservoirs cascade in 2022–2024, including the result of the Russian Federation's explosion of the Kakhovka HPP dam, which contributed to a significant increase in the content of suspended, humic substances in the Dnipro river water, an increase in river water colouring and the presence of a large amount of phyto- and zooplankton, made it impossible to use ammonia water disinfection technologies. In addition, the temporary occupation of part of Zaporizhzhia region led to the destruction of the logistics schemes for supplying Municipal Enterprise "Vodokanal" with coagulant (aluminium oxychloride), which was produced by the Polohy enterprise "Coagulant" and used in the ammonization processes for the preparation of drinking water at the Dnipro water supply stations 1 and 2.

Thus, providing the population of Zaporizhzhia city and the region with high quality drinking water has become an urgent hygienic, scientific, technical and social issue as never before.

Aim

To study the content of environmental toxins, organic compounds and heavy metals in surface and ground waters in the south-east of Ukraine near the frontline and to identify areas of high risk of pollution.

Materials and methods

Sampling 30 of groundwater and artesian water was carried out by professional hydrogeologists on November 9, 2024 near Tarasivka village (geographical coordinates: 47°46′41″N 35°26′36″E / 47.77806°N 35.44333°E) and near Vilne village (geographical coordinates: 47.57286 N 32.61995°E) of Komyshuvakha village, Orikhiv district, Zaporizhzhia region, at the depth of aquifers of 5, 14 and 190 metres, 10 samples at each depth.

The water was not preserved and was delivered to the laboratory within a few hours. When obtaining the samples, the requirements for preventing additional water contamination were followed in accordance with Order No. 30 dated by 19.01.2016 "On Approval of the Instruction on the Collection, Preparation of Water and Soil Samples for Chemical and Hydrobiological Analysis by Hydrometeorological Stations and Posts".

Water samples were collected by hydrogeologists and volunteers of the "World Against Cancer" fund from the drainage system near Vilne village, Zaporizhzhia region (geographical coordinates: 47.57286 N, 32.61995 E).

The chemical analysis was carried out in the laboratory of "Ukrkhimanaliz" LLC of the Center for Preventive Medicine of the State Administration of Affairs, which meets the requirements of State Standards of Ukraine EN ISO/IEC 17025:2019 and 10012:2005 "Measurement management systems and requirements for measurement processes and measuring equipment" – Certificate No. 10-007 dated by 16 September 2022. The water quality assessment was carried out in accordance with the state sanitary norms and regulations "Hygienic Requirements for Drinking Water Intended for Human Consumption" (State Sanitary Rules and Norms 2.2.4-171-10), which is the only regulatory document on the quality of drinking water indicators in Ukraine.

The water content of silicon, cobalt, lead, chromium, bismuth, copper, mercury, iron, zinc, cadmium, nickel, manganese, potassium, calcium, magnesium, sodium, aluminium was determined by the atomic emission spectral method and compared with the maximum permissible concentration (MPC) for drinking water.

The presence of oil products, formaldehyde, phenol, ammonium, nitrites, and sulphates was determined by photometric method.

Permanganate oxidation, chlorides and hydrocarbons were evaluated by the titrimetric method; cyanides, polyphosphates, iodine, fluorine, water pH – by ionometric method; sulphides by colorimetric method; pesticides – by chromatographic method.

Dissolved oxygen and oxidation-reduction potential of water were measured by ionometric method, total organic carbon was measured by calculation.

The study to determine chloroform in drinking water to assess the health risk to the population of Zaporizhzhia city and Zaporizhzhia district was conducted by leading experts of the State Institution "Zaporizhzhia Regional Center for Disease Control and Prevention of the Ministry of Health". The content of trihalogen methanes (THMs), namely chloroform (CHCl3), bromodichloromethane (CHBrCl2), and dibromochloromethane (CHBr2Cl) was determined in the drinking water of Zaporizhzhia and Zaporizhzhia district. The study was carried out in accordance with State Sanitary Rules and Norms 2.2.4-171-10 Chromatographic Method for the Determination of Organochlorine Compounds according to State Standards of Ukraine ISO 10301-2004. The quantitative determination of trihalogen methanes was carried out using a TRECE 1610 (made in the USA) gas chromatography device.

The data obtained were statistically processed using Statistica software (licence No. JPZ804I382130ARCN10-J). Continuous variables are presented as mean ± standard error (M ± m). Minimum statistical significance was determined at $p < 0.05$.

Results

The hygienic assessment of groundwater quality and safety was carried out according to sanitary and chemical indicators, namely organoleptic, physicochemical and sanitary-toxicological indicators. It was established that groundwater at a depth of 5 and 14 meters does not meet the current standards for organoleptic, physicochemical and sanitary-toxicological indicators of drinking water quality.

At a depth of 190 meters (interlayer aquifer), chemical pollutants in artesian water were not found, and all the determined indicators met sanitary requirements *(Table 1)*.

In the water samples taken at a depth of 5 and 14 meters, the physicochemical parameters did not meet the standards for chlorides (exceeded by 1.1 times in both water samples), sulphates (exceeded by 6.2 and 7.3 times, respectively), total hardness (exceeded by 2.5 and 2.8 times, respectively), which is due to the presence of high levels of calcium and magnesium salts in the water – very hard water (more than 10.0 mmol/dm^3). The presence of high concentrations of soluble salts (exceeding 3.6 times at a depth of 5 meters and 4.5 times at a depth of 14 meters) contributes to the high level of water mineralization and classifies this water as highly mineralized. This feature is due to the complex and diverse composition of the hydrochemical zones of groundwater in the Azov-Dnipro region: hydrocarbonate-calcium sulphate, sodium sulphate-hydrocarbonate-calcium, etc. The assessment of anthropogenic water pollution in such

Table 1. Groundwater quality indicators in eastern Ukraine at 5, 14 and 190 meters near the frontline

Indicator, units of measurement	5 meters, n = 10	15 meters, n = 10	190 meters, n = 10	MPC	Method
Permanganate oxidisability, mg/dm^3	3.56 ± 0.02	3.74 ± 0.02	2.85 ± 0.03	<5	SSU 27384:2005
Total hardness, $mmol/dm^3$	25.25 ± 0.51*#	27.75 ± 0.98*#	0.30 ± 0.02	<10	SSU ISO 6059:2003
Salt content, mg/dm^3	5459.0 ± 218.0*#	7194.0 ± 190.0*#	51.0 ± 2.9	<1500	MVV 081/12-0109-03
Total alkalinity, $mmol/dm^3$	7.10 ± 0.21*#	7.40 ± 0.29*#	0.50 ± 0.03	<6.5	SSU ISO 9963-1:2007
Dry residue, mg/dm^3	5437.00 ± 238.00*#	7171.00 ± 253.00*#	49.00 ± 1.95	<1500	MVV 081/12-0109-03
Nitrates, mg/dm^3	80.60 ± 2.70*#	172.00 ± 4.40*#	2.86 ± 0.16	<50	MVI 081/37-0699-10
Chlorides, mg/dm^3	393.50 ± 4.89*#	400.59 ± 5.02*#	10.64 ± 0.32	<350	SSU ISO 9297:2007
Sodium, mg/dm^3	772.80 ± 14.10*#	964.80 ± 28.50*#	5.47 ± 0.21	<200	SSU ISON 11885:2019
Sulphates, mg/dm^3	3118.0 ± 88.9*#	3664.0 ± 86.7*#	–	<500	MVI 081/37-700-10
Calcium, mg/dm^3	611.19 ± 24.10*#	711.38 ± 12.80*#	0.56 ± 0.02	<130	SSU ISO 6059:2003
Magnesium, mg/dm^3	244.0 ± 8.5*#	243.10 ± 6.00*#	1.22 ± 0.30	<80	SSU ISO 6059:2003
Aluminium, mg/dm^3	0.08 ± 0.01	0.14 ± 0.02*	–	<0.1	SSU ISO 11885:2019
Iron, mg/dm^3	0.24 ± 0.02#	0.14 ± 0.01#	0.06 ± 0.01	≤1	MVI 081/37-0734-11
Silicon, mg/dm^3	9.44 ± 0.38#	9.59 ± 0.36#	1.10 ± 0.02	≤10	SSU ISO 11885:2019

***:** an indicator that exceeds the maximum permissible concentration according to Sanitary Rules and Norms 2.2.4-171-10 "Hygienic Requirements for Drinking Water Intended for Human Consumption"; **#:** statistically significant differences in the studied parameters of groundwater from shallow depths (5 and 15 meters) compared to deep water parameters (190 meters) ($p < 0.05$).

Table 2. THMs content in drinking water in Zaporizhzhia city (n = 70)

CAS	Substance	Concentration, $\mu g/dm^3$		Multiplicity of excess, times		MPC, $\mu g/dm^3$
		Medium	Maximal	Medium	Maximal	
67-66-3	Chloroform	208.24 ± 23.39	397.90	3.47	6.63	60.0
75-27-4	Bromodichloromethane	92.91 ± 6.41	133.65	3.10	4.46	30.0
124-48-1	Dibromochloromethane	15.16 ± 3.57	44.70	1.52	4.47	10.0
Total THM		232.21 ± 37.71	551.59	2.32	5.52	100.0

biogeochemical provinces is complicated and requires more detailed study.

The unsatisfactory water quality in terms of sanitary and toxicological indicators is due to high levels of nitrates (exceeding 1.6 times at a depth of 5 meters and 3.4 times at a depth of 14 meters), aluminium (exceeding 1.4 times at a depth of 14 meters) and sodium (exceeding 3.9 times at a depth of 5 meters and 4.8 times at a depth of 14 meters).

Inconsistency in the chemical composition of water can cause non-communicable diseases: high hardness – urinary stone disease, cholelithiasis, gout; high nitrate content – water-nitrate methemoglobinemia, nitrosamines – malignant tumors; high aluminium content – diseases of the central nervous system; high mineralization – diseases of the cardiovascular system, water and electrolyte imbalance, disorders of the secretory activity of the gastrointestinal tract, etc.

Phenols, formaldehyde, petroleum products, polyphosphates, cyanides, sulphides, surface active substances, pesticides, or heavy metals such as bismuth, copper, mercury, cadmium, nickel, cobalt, lead, or chromium were not found in the water samples. The level of silicon did not exceed the permissible limit.

When assessing the quality of drinking water in the city of Zaporizhzhia since the beginning of hostilities (2023), an increase in the MPC of chloroform in drinking water was recorded (Rules and Norms 2.2.4-171-10). The calculated risk from the use of such drinking water for public health was 3.348×10^{-4}, which belongs to the third risk range and is considered acceptable for professional groups, but not acceptable for the general population and requires the development and implementation of measures to reduce it (WHO International Standard of Drinking Water. USA, 2002).

In 2024, out of 70 samples of drinking water taken from the centralized water supply networks of the Municipal Enterprise "Vodokanal" and Enterprise of State Criminal-Executive Service of Ukraine, 67–96 % did not meet the hygiene standards for THMs according to the Sanitary and Epidemiological Standards "Safety Indicators and Certain Indices of Drinking Water Quality in Martial Law and Other Emergency Situations", approved by the Order of the Ministry of Health of Ukraine of 22.04.2022 No. 683 and the State Sanitary Rules and Norms "Hygienic Requirements for Drinking Water Intended for Human Consumption" (State Sanitary Rules and Norms 2.2.4-171-10).

The formation of THMs can be influenced by many factors, including the nature of organic compounds in natural water, pH, temperature, nature and dosage of the chlorinated agent, duration of chlorination, time of year, etc. However, the main reason is primarily an excessive content of organic substances in the natural source, including humic substances, sulfonic acids, amino acids, tannins, quinones, and carbohydrates.

In Ukraine, the following permissible concentrations of THMs in drinking water are established: CHCl – 60 μg/dm^3, $CHBr_2Cl$ – 10 μg/dm^3, total THM – 100 μg/dm^3.

Sampling of drinking water in Zaporizhzhia city and determination of the THMs content in drinking water was carried out in accordance with the drinking water quality monitoring plan. The results are presented in *Table 2*.

To assess the exposure and the level of carcinogenic risk to public health from exposure to volatile organochlorinated compounds, namely THMs, including all possible routes of their entrance into the human body (oral, inhalation and dermal) were taken into account. The carcinogenic risks for the three routes of drinking water chloroform entrance were calculated according to the formulas given in Guideline P. 2.1.10.1920-91 "Guidelines for Assessing the Risk to Public Health from Exposure to Environmental Chemicals". Individual carcinogenic risks were determined taking into account the lifetime average daily dose avenged for the average human life expectancy (70 years) and the carcinogenic potential factor or slope factor, which is determined in accordance with the IRIS and HEAST US EPA databases.

It has been established that the dependence of the individual risk (oral, inhalation, dermal) on the content of THMs in drinking water is linear, which allowed the use of linear regression models and obtain formulas for calculating the individual carcinogenic risk for three ways of drinking water total THM exposure.

For average THMs concentrations they were: for oral rout of entry: $Yo = 3.8 \times 10^{-2}$; for inhalation route of entry: $Yi = 6.9 \times 10^{-2}$; for the dermal route of entry: $Yd = 1.1 \times 10^{-2}$. For the maximum THMs concentrations they were: for oral rout of entry they were: $Yo = 9.2 \times 10^{-2}$; for inhalation route of entry: $Yi = 16.5 \times 10^{-2}$; for the dermal route of entry: $Yd = 2.7 \times 10^{-2}$.

When assessing carcinogenic risk, its generally accepted classification into four risk ranges is taken into account in accordance with the WHO approaches to human health risk assessment (International Standard of Drinking Water. USA-2002). According to the calculations of individual carcinogenic risk, chlorinated tap water in Zaporizhzhia city and Zaporizhzhia district belongs to the fourth risk range (De Manifestis Risk) – individual lifetime risk is equal to or greater than 1×10^{-3}. Such a risk is unacceptable neither for the general population nor for professional groups. In case of such a risk it is necessary to take emergency health measures to reduce the risk.

According to WHO experts, the target risk value is 1×10^{-6}. In Ukraine, the permissible risk for drinking water is 1×10^{-5}, and the target risk is 1×10^{-5}–1×10^{-6} (according to WHO recommendations). The upper limit of acceptable carcinogenic risk for Group A carcinogens (THM) is 1×10^{-5}, or the rest – 1×10^{-4}.

Discussion

Today, planet Earth has about 1400 million cubic kilometers of water, but only 0.5% is fresh and available for consumption. 99 % is in groundwater, which is one of the most important natural resources, but it is extremely vulnerable to pollution even in peacetime [9].

War causes mechanical and chemical pollution of surface water reservoirs and groundwater. During hostilities, heavy metals (copper. iron, lead, zinc, arsenic) remain on the ground surface for many decades after the detonation of landmines and ammunition remnants and can enter groundwater for a long time [10,11,12].

Depleted uranium, which is a chemically active substance, can be an additional pollutant from the group of heavy metals. Therefore, there is also a radioactive threat to groundwater in Ukraine [13].

During hostilities, exposure to per- and polyfluoroalkyl substances (PFAS) is dangerous [14].

Thousands of tons of metals from flooded military equipment, missiles and shells are in Ukraine's rivers and reservoirs. where they corrode and poison aquatic ecosystems. Iron bioaccumulation is dangerous even at low concentrations [15].

Flooded military equipment emits hundreds of liters of petroleum products (diesel fuel, petrol, oils, greases). These hydrocarbons in their various migratory forms (assimilation by aquatic organisms, deposition, emulsification, formation of oil aggregates, oxidation, dissolution and evaporation) are extremely toxic to the environment.

Oil slicks concentrate other pollutants, heavy metals and pesticides, that create conditions for various chemical reactions that disrupt the biological structures of ecosystems [16].

The main hazardous pollutants include explosives such as TNT (2,4,6-trinitrotoluene). It is highly chemically stable and can remain in the soil for years, causing long-term effects on vegetation and human health. The trinitrotoluene derivative DNT (2,4-dinitrotoluene) is even more toxic. It is listed by the US Environmental Protection Agency as a priority contaminant in the aquatic environment [17,18].

RDX, Royal Demolition Explosive (hexahydro-1,3,5-trinitro-1,3,5- triazine), also known as cyclonite or hexogen, is an ingredient in explosives. It is a chemically and thermally stable hazardous compound that is prone to migration in groundwater. Hexogen is a synthetic product that does not occur in the natural environment [19].

Ammonium perchlorate, a component of rocket fuel, also causes significant and long-term water pollution.

Data from the UN Office for the Coordination of Humanitarian Affairs and research by Ukrainian ecologists indicate that from the first days of the war, the impact on Ukraine's aquatic ecosystems has been extraordinary [20,21]. It is estimated that in 2022 alone, 16 million Ukrainians were left without access to quality water [22,23].

Ukraine is one of the European countries with a shortage of water resources suitable for use in the national economy. In the east of the country, the Dnipro River is the largest source of water supply, and its pollution with heavy metals, organic substances and bacteria has continued to grow over the past two years.

During the war, shells, multiple rocket launchers, tanks, infantry fighting vehicles, and fragments of bridges and other structures ended up in the Dnipro and its tributaries.

Monitoring of drinking water is extremely important today Such work is constantly carried out by public services and specialists of the Institute of Public Health named after O. M. Marzieiev of the National Academy of Medical Sciences of Ukraine within the framework of the project "Safe Drinking Water in Ukraine: Access to Information on Water Quality and Water Treatment Methods", implemented by WaterNet with the financial support of the Finnish Local Cooperation Fund of the Embassy of Finland in Ukraine [24].

The authors of the project note that sampling from municipal water supply systems, boreholes and wells is carried out evenly across all regions of Ukraine, except for the temporarily occupied territories. The researchers emphasize that the situation with the availability of drinking water in some eastern regions of Ukraine is almost unknown today. The absence of a centralized water supply system in the areas near and in the zone of active hostilities, due to its destruction and the inability to operate treatment facilities and supply drinking water, forces the population living in these areas to use groundwater from wells as one of the main sources of water supply.

In Zaporizhzhia region, in addition to increased turbidity, the water has a high level of salts, such as calcium, magnesium, chlorides, sulphates, as well as a mismatch of sanitary and toxicological indicators (nitrates, aluminium, sodium), which significantly exceed the regulatory requirements. The lack of information on the interconnection of upper and deeper aquifers in the areas of hostilities remains a serious problem.

Since the start of the full-scale invasion, the international organisation CEOBS (Conflict and Environment Observatory) and other organisations have been remotely monitoring, assessing and mapping Ukraine's groundwater to determine its vulnerability [25,26].

To measure this indicator, a desktop approach was used, and a national groundwater map was created. This model, known as DRASTIC, was developed by the US Environmental Protection Agency. It considers the depth of groundwater, recharge in the aquifer, aquifer type, soil type, topographic slope, the influence of overlying rock types, and hydraulic conductivity. The permeability of an aquifer is a key factor that predicts whether pollutants can enter groundwater and poison it [22,27].

CEOBS experts emphasize that "remote assessments of groundwater vulnerability usually do not take into account the nature of specific contaminants, their concentration, or how quickly they can spread in the environment". They believe that in order to answer these questions, field sampling and consistent collection of environmental and geological information should be conducted [28].

Understanding the importance of environmental monitoring, we conducted field sampling of groundwater and artesian water and found significant contamination of aquifers near the frontline. It may be related to both natural and man-made factors caused by the hostilities.

An increase of more than 6 times in total salt content indicates high water salinity. In the case of man-made pollution, this can be the result of leakage of industrial or agricultural chemical waste, groundwater contamination from destroyed infrastructure, or salt rise from deep horizons due to soil destruction.

High nitrate content (3 times higher than normal) can be caused by agricultural fertilizers, decomposition of organic matter or sewage. Chloride can be an indicator of local contamination due to spills or leaks from munitions. A high sodium content may indicate leaching of salts from destroyed industrial facilities or soil. High levels of sulphate (7 times higher than normal) may be due to industrial emissions or decomposition of organic matter. High levels of calcium and magnesium (6 and 3 times higher than MPC) can be caused by damaged building materials and natural barriers, or by the destruction of surface soil horizons. Elevated aluminium content can result from leaching of the metal from the soil, especially if there are processes associated with the destruction of its layers. Aluminium can also be linked to soil pollution originating from industrial activities. It is acknowledged as a neurotoxicant, strongly associated with several neurodegenerative disorders. The mechanism of its detrimental impact has been identified, involving the activation of microglia and an elevation in extracellular ATP levels, stimulation of P2X7 receptors, HIF-1α, activation of the NLRP3 inflammasome and CASP-1, along with the release of elevated concentrations of the cytokine IL-1β, triggering an inflammatory response in nervous tissue [29].

Water from the upper aquifers can be recharged more quickly by rain and surface runoff, which can be contaminated by warfare, while the deeper aquifers are more protected as they are located between two waterproof layers.

Hostilities accompanied by chemicals' leaks or the destruction of facilities can affect deep water layers, with the destruction of impermeable soil layers. Pollutants such as nitrates and heavy metals can gradually seep downwards, creating zones of concentrated pollution at great depths. Epidemiologic studies of factors contributing to drinking water and associated health risks have been conducted, especially in relation to clinical observations linked to colorectal cancer, bladder cancer, and thyroid disorders [30].

If the soil layers are damaged by vibrations or explosions, this allows pollutants to penetrate deeper horizons more quickly.

Changes in the chemical composition of water in the surface and deeper aquifers may indicate environmental degradation. War, destruction of infrastructure, leakage of fuel, chemicals and ammunition, as well as agricultural and domestic pollution, exacerbate the negative impact on water resources and increase the risk of chronic diseases in the population.

It is important to note that it is currently impossible to assess the full extent of the destruction of water resources in the area of hostilities.

The environmental consequences of the war will be long-term. It is predicted that the restoration of water infrastructure, forests and agriculture in the areas that have been destroyed will take a lot of time and resources [31,32].

A geological survey should be conducted to determine the condition and possible changes in the water-resistant layers caused by the hostilities.

Hydrogeological modelling should be used to understand the ways of pollutants spreading in the eastern regions of Ukraine.

The deterioration of deep water quality can be an important indicator of the long-term impact on the region's ecology.

The main goal today is to ensure continuous monitoring of the quality of air, soil, surface and groundwater, to prevent the ecocide from continuing, and to develop a state plan for the restoration of Ukraine in cooperation with the international community [33].

Conclusions

1. Groundwater in Zaporizhzhia region near the front line at a depth of 5 and 14 meters is of unsatisfactory quality in terms of organoleptic characteristics (turbidity), physicochemical characteristics (high total hardness, high mineralization) and sanitary and toxicological characteristics (high concentration of nitrates, aluminium and sodium), which makes it unsuitable for drinking. The artesian water, which is located at a depth of 190 meters from the surface, does not contain any man-made pollutants in the area and is suitable for drinking.

2. The peculiarities of the physicochemical parameters of the selected groundwater samples, namely high levels of mineralization, sodium content, sulphate content and total hardness, may be due to both biogeochemical features of the soil composition of the area and anthropogenic pollution. High levels of nitrates and aluminium indicate the presence of anthropogenic sources of water pollution.

3. In terms of individual carcinogenic risk, chlorinated tap water in Zaporizhzhia city and Zaporizhzhia district belongs to the fourth risk range (De Manifestis Risk) – individual lifetime risk is equal to or greater than 1×10^{-3}. This level of risk is unacceptable both for the population and professional groups and requires emergency risk reduction measures.

4. To reduce carcinogenic risks to the population, it is recommended to use preammonification processes when disinfecting drinking water with chlorine. If preammonification is not possible, use disinfectants that have less carcinogenic properties. Establish a scientifically based standard for the chloroform content in drinking water instead of the standard of ≤300 mg/dm^3, which is provided by the Sanitary and Epidemiological Standards "Safety Indicators and Certain Indices of Drinking Water Quality in Martial Law and Other Emergency Situations", approved by Order of the Ministry of Health of Ukraine No. 683 dated by 22.04.2022.

Prospects for further research. It is planned to continue studying the wartime contamination of surface and groundwater, air and soil with toxins and carcinogens in the area of hostilities to assess the long-term impact on the health of the population of eastern Ukraine and the increased levels of environmental risks, including cancer. It is also planned to conduct long-term cancer epidemiological and preclinical studies, including cell culture experiments, on the impact of water pollutants on the risk of developing certain types of cancer in humans.

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