Проблеми екології та медицини

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ORIGINAL RESEARCH/ОРИГІНАЛЬНІ ДОСЛІДЖЕННЯ

RISK ANALYSIS OF WATER-NITRATE METHEMOGLOBINEMIA IN THE HYGIENIC MONITORING SYSTEM OF DECENTRALIZED WATER SUPPLY SOURCES

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In the context of numerous water and environmental challenges, nitrate contamination of well water stands out as a particularly urgent concern, posing a significant risk for the development of water-nitrate methemoglobinemia – especially in young children.

This study **aimed** to conduct a comprehensive risk assessment of this condition associated with elevated nitrate levels in decentralized water supply sources in the Kharkiv region and to develop a scientifically grounded set of preventive measures.

Materials and methods. A retrospective analysis was conducted on laboratory monitoring data of well and spring water quality in the Kharkiv region, alongside an age- and sex-based statistical analysis of methemoglobinemia incidence.

Results. A systemic issue of nitrate contamination in well water was identified, with the proportion of samples exceeding permissible nitrate levels ranging from 37.7% to 47.2%, and an average non-compliance rate of 42.2 ± 3.22%. Additionally, an age- and sex-based analysis of water-nitrate methemoglobinemia cases was conducted. It was found that the concentration of nitrates in the water that caused the poisoning ranged from 51 to 530 mg/dm³, with an average value of 287.3±146.14 mg/dm³. The maximum concentration of cases occurred in the first year of life (70 %), of which 25 % were recorded in the group of infants under 1 month of age.

Conclusions. This article highlights the ongoing issue of nitrate contamination in decentralized water supply sources in the Kharkiv region, which poses a continuous risk of water-nitrate methemoglobinemia, particularly among young children. Addressing this challenge requires a comprehensive strategy that includes strengthening the water quality monitoring system, establishing an early warning mechanism for hazardous contamination levels, and raising public awareness about the risks of consuming polluted water and available treatment methods.

Keywords: water-nitrate methemoglobinemia, drinking water quality, nitrate pollution, decentralized water supply, health care, preventive measures.

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Introduction

The problem of providing the population with drinking water of high quality is one of the priority areas of Ukraine's public health policy. This problem is particularly relevant for rural areas, where individual and public wells remain the main source of drinking water supply. According to the State Agency of Ukraine for Water Resources, about 5.7 million people use water from decentralized water sources, and the quality of this water often does not meet hygiene requirements [13]. Given the intensification of agriculture and the growing anthropogenic pressure on water resources, the problem of nitrate pollution of groundwater is becoming particularly relevant.

Water-nitrate methemoglobinemia poses a particular danger to public health, especially to young children. The pathogenesis of the disease is associated with the oxidation of ferrous haemoglobin to trivalent iron under the influence of nitrite, which is formed from nitrate under the influence of the gastrointestinal microflora. This leads to impaired oxygen transport and tissue hypoxia. In infants, the risk of developing water-nitrate methemoglobinemia is much higher due to the peculiarities of enzyme systems and the pH of gastric juice, which promotes the active reduction of nitrates to nitrites. Clinical manifestations include cyanosis, tachycardia, dyspnoea, and in severe cases, impaired consciousness and death [19]. A significant number of cases of poisoning have been reported in infants who received food prepared using water (mainly based on milk powder mixtures or breast-milk substitutes) or foods with a high nitrate content.

Elderly people and patients with pathologies of the respiratory and cardiovascular systems, as well as those suffering from anaemia, also demonstrate increased sensitivity to the toxic effects of nitrates. With prolonged intake of nitrates, there are disruptions in the functioning of the endocrine system, central nervous system and circulatory system, including the development of thyroid pathologies [18].

The impact of nitrates on reproductive health is of particular concern. In pregnant women, nitrate intoxication can lead to embryonic developmental disorders and foetal death. In men, chronic exposure to nitrates is associated with impaired spermatogenesis, which can be a factor in the development of infertility [10].

Studies confirm the immunosuppressive properties of nitrates, which reduce the body's resistance to carcinogenic and mutagenic factors. This, in turn, can lead to the development of various pathological conditions and a shorter life expectancy. Scientific evidence also suggests the carcinogenic potential of nitrates and nitrites: with prolonged exposure, they can stimulate the development of gastric malignancies and increase the risk of colorectal cancer, even at concentrations that do not exceed current regulatory levels [6,16]

According to the WHO, the problem of nitrate water pollution is global. The US Environmental Protection Agency reports that about 15% of private wells exceed the permissible nitrate level of 10 mg/L [20]. EU Member States report a relatively good state of groundwater resources. According to hydrochemical monitoring data, approximately 77 % of aquifers exhibit a favorable chemical profile, indicating a relatively stable ecological balance of hydrogeological systems. However, according to the European Agency, there is an issue of anthropogenic groundwater pollution, primarily associated with nitrates [7]. In India, according to a study by the Central Ground Water Board, almost 40 % of groundwater tested in agricultural regions contains nitrates above the permissible level [2,17]. The Australian Water Resources Agency recorded exceedances of nitrate standards in 23 % of groundwater samples in intensive farming regions [1]. In China, national water quality monitoring found that approximately 30 % of rural water sources have elevated nitrate levels [11].

The main sources of nitrates in groundwater are excessive use of nitrogen fertilisers, livestock waste, municipal wastewater and precipitation [14]. Intensification of agriculture leads to an increase in nitrate pollution of groundwater, which creates additional risks to public health [4,12]

According to national and international standards, the maximum permissible concentration of nitrates in drinking water is 50 mg/L [3,15]. Exceeding this level poses a potential risk to public health, especially for children in the first year of life.

The aim of the study was to comprehensively assess the water quality of the decentralized water supply in Kharkiv region in terms of nitrate content, identify areas at high risk of water-nitrate methemoglobinemia, conduct a statistical age-sex analysis of the incidence of methemoglobinemia among the population of Kharkiv region, and develop a scientifically grounded set of preventive measures based on the analysis of long-term monitoring data.

Materials and methods

A retrospective hygienic study was conducted using laboratory monitoring data on water quality from wells and spring sources in the Kharkiv region from 2017 to 2023. Nitrate concentrations were measured in accordance with DSTU 7525:2014 [5]. Additionally, a statistical age-gender analysis of methemoglobinemia incidence was performed based on data from the State Institution "Kharkiv Regional Center for Disease Control and Prevention, Ministry of Health of Ukraine." Statistical analysis was car-

ried out using Microsoft Excel 2019, with correlation analysis conducted via Spearman's rank test.

Results

Long-term monitoring of the quality of drinking water from decentralized water supply sources in Kharkiv Region over the period 2017–2023 has revealed a systemic problem of nitrate contamination of well water. This poses a persistent and serious threat to public health, especially to young children. The urgency of this situation cannot be overstated. Table 1 shows the number of water samples examined and the proportion of water samples with exceeded nitrate concentrations during the monitoring period.

The analysis of the dynamics of research shows a significant decrease in the total number of water samples – from 4646 in 2017 to 345 in 2023. This decrease reflects a reduction in the intensity of monitoring, primarily due to the ongoing war and intense hostilities in certain parts of the Kharkiv region.

Tabl. 1.
Dynamics of compliance of well water with the standard nitrate contentю

Year	Total of samples	Samples with excessive nitrate content	
		Absolute value	%
2017	4646	2134	45.9
2018	3054	1348	44.1
2019	2543	1035	40.7
2020	1619	642	39.7
2021	1476	649	44.0
2022	726	314	43.3
2023	345	130	37.7

However, it is crucial to emphasize the need for increased monitoring, especially in these areas, to ensure the safety of the water supply. At the same time, the number of well water samples with exceeded nitrate concentrations was also decreasing (Fig. 1).

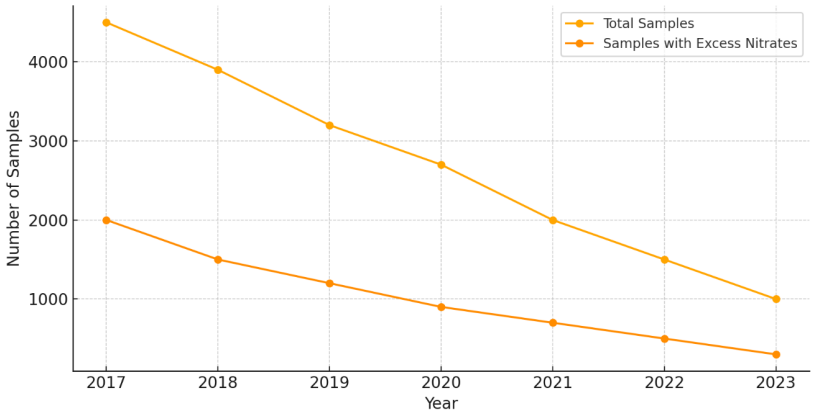

Fig. 1. Dynamics of the depth of water quality monitoring in decentralized water supply sources in Kharkiv Region for 2017–2023.

Despite the significant reduction in the number of studies, the percentage of water samples with an increased nitrate content remains consistently high, ranging from 37.7 to 47.2%, which indicates the systemic nature of the pollution problem. The average non-compliance rate with hygiene standards, which are set to ensure safe water consumption, for the entire study period is 42.2±3.22%, meaning that almost half of the water sources studied pose a potential danger to consumers (Fig. 2).

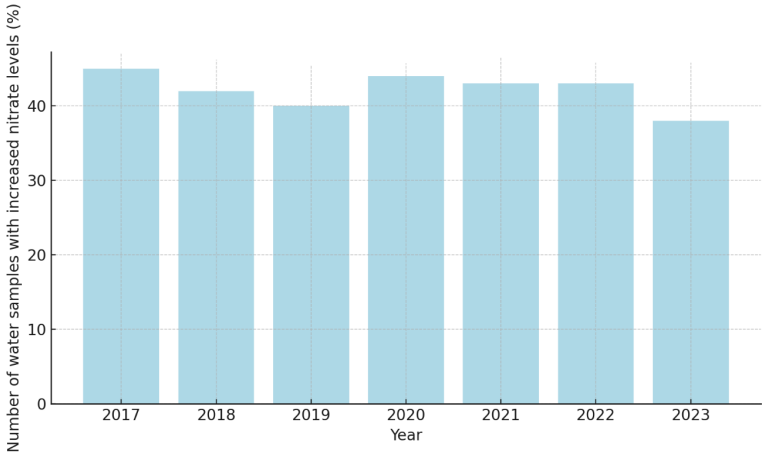

Fig. 2. Dynamics of the relative number of water samples with an increased nitrate content during the observation period.

The territorial distribution of pollution is particularly noteworthy. Areas with a systematically high percentage of water samples with an increased nitrate content that exceeds the regional average were identified (Tabl. 2).

Tabl. 2.
Statistics on the relative number of water samples with exceeded nitrate content during the observation period.

District of Kharkiv region	Range of the proportion of samples with exceeding nitrate content, %	Average value, %
Derhachi district	57.4–68.9	63.15±5.7
Valky district	60.9–87.6	74.25±13.35
Lozova district	70.0–83.9	76.95±6.95
Kharkiv district	34.0–75.0	54.5±20.5

The statistical processing of the number of water samples that do not meet hygienic standards for nitrate content allows us to conclude that there is a steady trend towards maintaining a high level of nitrate pollution in the listed areas throughout the observation period. Nitrate concentrations in water samples exceeded the maximum permissible concentration by 1.2 to 17.6 times in different years, indicating a critical pollution level from certain sources.

An analysis of cases of water-nitrate methemoglobinemia for the period 2013–2023 revealed a total of 20 reported cases. The distribution of cases by year demonstrates an uneven pattern: in some years, there were 5 cases of methemoglobinemia (2013), and in some years, there were none (2018, 2021 and 2023). The nitrate concentration in the water that caused the poisoning ranged from 51 to 530 mg/dm³, with an average value of 287.3±146.14 mg/dm³.

In addition, we conducted an in-depth analysis of the age and sex distribution of the incidence of water-nitrate methemoglobinemia in the Kharkiv region. The analysis of morbidity patterns within the pediatric population revealed a complex demographic distribution of this pathology. The statistical analysis of retrospective data allows us to establish a low number of fundamentally important patterns in the age and gender differentiation of morbidity.

A key characteristic of the situation is the uneven distribution of methemoglobinemia cases across different age groups (Fig. 3). The highest incidence was observed during the first year of life, accounting for 70% of cases, with one in four cases occurring in infants under one month old. No significant age-related differences were found within this group (60% of patients in this age group were boys and 40% were girls).

In general, the first six months of life account for a significant proportion of diseases (35%), and the same percentage is typical for the next period, 6 months to 1 year. This period is characterized by fundamental changes in the child's diet (introduction of complementary foods) and microbiome formation. In this age group, there was also some disproportion with a prevalence of morbidity among boys (57%) compared to girls (43%). The lowest incidence (10%) was recorded from 1 to 6 months, with a symmetrical distribution between the sexes (50% each). This phenomenon may be related to the peculiarities of development and improvement of the body's enzyme systems.

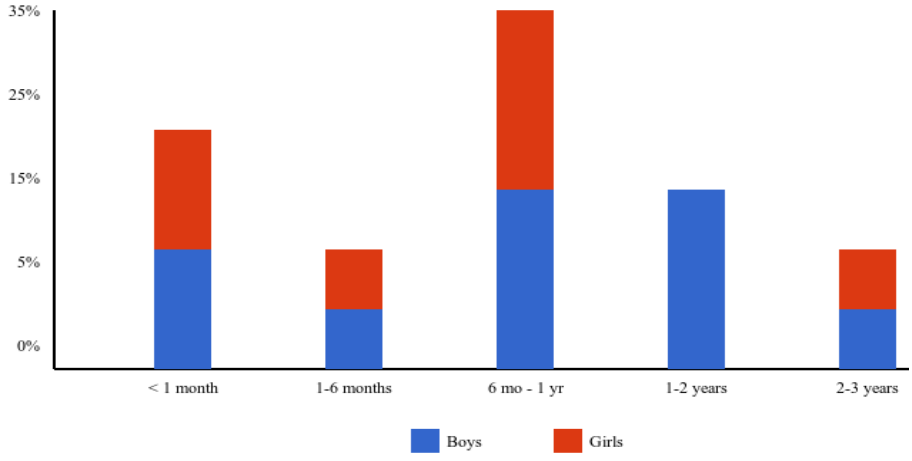

Fig. 3. Age and gender distribution of methemoglobinemia cases.

Particular attention was drawn to the age group "1–2 years," with 15% of cases, where all diseases were diagnosed in male children. Generally, the overall proportion of boys was higher than that of girls. However, given the statistically small number of patients, we cannot draw definitive conclusions

about the greater sensitivity of male children to the toxic effects of nitrates. This distribution requires further study regarding the influence of biological and social factors.

Discussion

A detailed analysis of the cases revealed several important patterns. Firstly, there is a clear seasonality – most cases were registered in the spring and summer, which may be due to increased leaching of nitrates into groundwater during spring snowmelt and rains and increased water consumption during the warm season. Secondly, a clear age dependence has been identified – the vast majority of those affected are children under 1 year of age, which is explained by the increased sensitivity of children's bodies to nitrate pollution. Thirdly, the geographical distribution of cases predominates in rural areas, where the population is more dependent on decentralized water sources.

The correlation analysis revealed a moderate positive correlation (r=0.48) between the number of cases of methemoglobinemia and the maximum recorded nitrate concentrations in water, which confirms the direct impact of pollution on the risk of the disease.

The analysis of the methemoglobinemia incidence confirms newborns' increased vulnerability to nitrate water pollution (in our study, the group under 1 month of age). This is due to the physiological characteristics of infants, in particular, the immaturity of enzymatic systems and the increased permeability of the blood-brain barrier, which determines high sensitivity to nitrate load [8]. The high sensitivity to nitrates and nitrites in children under 1 year of age is explained by the fact that they consume 4 times more fluid per unit of body weight than adults [9].

The identified imbalance in gender groups may indicate differential reactivity of substances and different mechanisms of nitrate biotransformation. An in-depth study of the age and gender structure of the incidence can help develop targeted preventive measures and optimize water quality monitoring in the region.

The results confirm the hypothesis of a complex etiopathogenesis of water-nitrate methemoglobinemia and indicate the need to develop differentiated prevention strategies considering the age and gender characteristics of the pediatric population of the Kharkiv region.

Several promising directions for further hygiene research have been identified:

1. In-depth investigation of the biochemical mechanisms of nitrate metabolism in children across different age and gender groups.

2. Comprehensive analysis of regional water supply characteristics and vulnerabilities.

3. Development of targeted preventive interventions based on identified risks.

Of particular concern is that the maximum permissible concentrations of nitrates in the water of the wells used by the affected families were significantly higher than the maximum permissible concentrations. In most cases, the concentrations exceeded the standard by a factor of 3 to 10, and in some cases by more than 15. This indicates the critical state of groundwater pollution in certain areas of the region and the need for urgent measures to improve the situation. According to our data, during the monitoring period, the most frequent exceedances of nitrates in well water were recorded in Lozova and Valky districts.

Therefore, it should be noted that the intensity of water quality monitoring decreased during the study period, which may lead to the under-detection of problematic water sources and potential risks to public health. Given the consistently high percentage of water samples with elevated nitrate levels, improving the water quality monitoring system is advisable, especially in areas with retrospectively high pollution levels.

The study's results also point to the need to develop and implement more effective water treatment methods from nitrates at the level of individual households, as complete replacement of water sources is unlikely in the short term. Another important aspect is to raise public awareness of water quality control methods and how to treat water at home. Increasing public awareness about the risks of nitrate contamination and the importance of safe water consumption is crucial. This will empower individuals to take necessary precautions and demand action from relevant authorities.

The problem of nitrate contamination of decentralized water supply sources in the Kharkiv region remains urgent and requires constant attention from healthcare, local government and environmental supervision authorities. It is necessary to develop a comprehensive program to improve drinking water quality, including technical measures to modernize water supply systems and educational components to raise public awareness of the risks of consuming contaminated water and methods to minimize them.

Conclusion

A persistent problem of nitrate contamination in decentralized water supply sources in the Kharkiv region has been identified, posing a continuous threat of water-nitrate methemoglobinemia, particularly among infants. Addressing this issue requires a comprehensive approach, including enhanced wa-

ter quality monitoring, the implementation of an early warning system for hazardous contamination levels, and public education on the risks of consuming polluted water and effective treatment methods.

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This study did not require ethical approval

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АНАЛІЗ РИЗИКУ ВИНИКНЕННЯ ВОДНО-НІТРАТНОЇ МЕТГЕМОГЛОБІНЕМІЇ В СИСТЕМІ ГІГІЄНІЧНОГО МОНІТОРИНГУ ДЖЕРЕЛ ДЕЦЕНТРАЛІЗОВАНОГО ВОДОПОСТАЧАННЯ

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Мета. В умовах наявності великої кількості водно-екологічних проблем особливої актуальності набуває проблема нітратного забруднення колодязної води, що створює ризик розвитку водно-нітратної метгемоглобінемії, особливо у дітей раннього віку. Метою дослідження була комплексна оцінка ризиків виникнення цього захворювання у зв'язку з підвищенням вмісту нітратів в джерелах децентралізованого водопостачання Харківської області та розробка науково обґрунтованого комплексу профілактичних заходів.

Матеріали та методи. Проведено ретроспективний аналіз даних лабораторного моніторингу якості води з колодязів та каптажів джерел Харківської області та статистичний віково-статевий аналіз частоти випадків захворювання на метгемоглобінемію.

Результати. Виявлено системну проблему забруднення колодязної води нітратами – відсоток проб води зі збільшеним вмістом нітратів коливався у межах 37,7 – 47,2 %, із середнім показником невідповідності гігієнічним нормам 42,2±3,22 %. Також проведено віково-статевий аналіз випадків водно-нітратної метгемоглобінемії. Встановлено, що концентрація нітратів у воді, що спричинила отруєння, варіювала від 51 до 530 мг/дм³ при середньому значенні 287,3±146,14 мг/дм³. Максимальна концентрація випадків захворювання припала на перший рік життя (70 %), з яких 25 % зафіксовано в групі немовлят віком до 1 місяця.

Висновки. Визначено стійку проблему нітратного забруднення джерел децентралізованого водопостачання в Харківській області, що створює постійну загрозу виникнення випадків водно-нітратної метгемоглобінемії, особливо серед дітей раннього віку. Ситуація потребує комплексного підходу до вирішення, включаючи посилення системи моніторингу якості води, впровадження системи раннього оповіщення про небезпечні рівні забруднення та проведення просвітницької роботи серед населення щодо ризиків споживання забрудненої води та методів її очищення.

Ключові слова: водно-нітратна метгемоглобінемія, якість питної води, нітратне забруднення, децентралізоване водопостачання, охорона здоров'я, профілактичні заходи.