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Катерина НЕСТЕРОВА
аспірант кафедри загальної, органічної та фізичної хімії, Національний університет біоресурсів і природокористування України, вул. Героїв Оборони, 15, м. Київ, Україна, 03041
***ORCID:** 0000-0003-4081-4570*

Олена ХИЖАН
кандидат хімічних наук, доцент, доцент кафедри загальної, органічної та фізичної хімії, Національний університет біоресурсів і природокористування України, вул. Героїв Оборони, 15, м. Київ, Україна, 03041
***ORCID:** 0000-0002-2986-3251*

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АНАЛІЗ ЕЛЕМЕНТНОГО СКЛАДУ ВОДНИХ РЕСУРСІВ КИЇВСЬКОГО РЕГІОНУ

Постійний контроль складу водних ресурсів є важливим для збереження екологічного балансу та захисту довкілля. Забруднення води важкими металами становить серйозну глобальну загрозу через їхню високу токсичність для живих організмів навіть у малих концентраціях. Тому надійне та точне визначення важких металів у воді необхідне для забезпечення її безпеки.

Дослідження проводилися в акредитованій випробувальній лабораторії Національного університету біоресурсів і природокористування України. Метою дослідження було оцінити вміст хімічних елементів, зокрема важких металів, у зразках води з різних джерел Київського регіону. Для цього було використано атомно-емісійну спектрометрію з індуктивно-зв'язаною плазмою (ICP-AES), що характеризується високою точністю та чутливістю.

Джерела забруднення важкими металами включають промислові викиди, агрохімікати, неналежну утилізацію відходів. Це сприяє накопиченню елементів у довкіллі, зокрема в повітрі, ґрунті та воді. Ефективне виявлення важких металів у воді є критичним для контролю якості.

Дослідження, проведені в Київській області, виявили, що концентрації металів, таких як кобальт, кадмій, свинець, нікель, хром, мідь, цинк, марганець, молібден, миш'як, ртуть, перебувають у допустимих межах. Отримані дані підтверджують, що якість води відповідає екологічним нормам і є безпечною для споживання.

Результати дослідження дозволяють розробити ефективні стратегії управління водними ресурсами, спрямовані на зниження ризиків забруднення важкими металами та збереження екологічної безпеки. Регулярний моніторинг дає змогу оперативно виявляти зміни у водних об'єктах і запобігати потенційним загрозам для здоров'я людей та екосистем.. Це вказує на стабільний екологічний стан водних ресурсів регіону. Вода придатна для використання без необхідності негайного зниження концентрацій цих металів.

***Ключові слова:** атомно-емісійна спектрометрія, важкі метали, вода.*

Kateryna NESTEROVA
PhD Student at the Department of General, Organic and Physical Chemistry, National University of Life and Environmental Sciences of Ukraine, 15, Heroiv Oborony str., Kyiv, Ukraine, 03041
***ORCID:** 0000-0003-4081-4570*

Olena KHYZHAN
Candidate of Chemical Science, Associate Professor, Associate Professor at the Department of General, Organic and Physical Chemistry, National University of Life and Environmental Sciences of Ukraine, 15, Heroiv Oborony str., Kyiv, Ukraine, 03041
***ORCID:** 0000-0002-2986-3251*

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ANALYSIS OF THE ELEMENTAL COMPOSITION OF WATER RESOURCES OF KYIV REGION

Continuous monitoring of water resources is crucial for maintaining ecological balance and protecting the environment. Water pollution by heavy metals poses a significant global threat due to their high toxicity to living organisms, even at low concentrations. Therefore, reliable and accurate detection of heavy metals in water is essential to ensure its safety.

The research was conducted at an accredited testing laboratory of the National University of Life and Environmental Sciences of Ukraine. The study aimed to assess the content of chemical elements, particularly heavy metals, in water samples from various sources in the Kyiv region. Inductively coupled plasma atomic emission spectrometry (ICP-AES), known for its high precision and sensitivity, was utilized.

Sources of heavy metal pollution include industrial emissions, agrochemicals, and improper waste disposal, contributing to the accumulation of these elements in the environment, especially in air, soil, and water. Effective detection of heavy metals in water is critical for quality control.

Research conducted in the Kyiv region revealed that the concentrations of metals such as cobalt, cadmium, lead, nickel, chromium, copper, zinc, manganese, molybdenum, arsenic, and mercury are within acceptable limits. The findings confirm that water quality complies with ecological standards and is safe for consumption.

The study's results enable the development of effective water resource management strategies aimed at reducing the risks of heavy metal pollution and ensuring ecological safety. Regular monitoring allows for timely detection of changes in water bodies and helps prevent potential threats to human health and ecosystems. This indicates a stable ecological state of the region's water resources. The water is suitable for use without the immediate need for reducing the concentrations of these metals.

Key words: *atomic emission spectrometry, heavy metals, water.*

Introduction. Heavy metals toxicity in water is a serious threat to human health. Metals like lead, mercury, cadmium, and even aluminum do not play a biological role in the human body and can negatively affect metabolic processes, causing severe illnesses. These metals enter the human body through water and can interfere with natural chemical processes by blocking essential enzymes or replacing vital elements, resulting in dysfunction of organs and systems. Lead, for instance, can replace calcium in the bones and brain, posing a particular danger to children, causing nervous system disorders and cognitive impairments. Mercury and cadmium accumulate in organs and cause chronic toxicity, affecting the kidneys, liver, and other vital systems. The toxicity of heavy metals depends on the duration and intensity of exposure. Even regular intake of small doses of heavy metals can lead to their gradual accumulation in the human body thus increasing oxidative stress. It is a process that damages cell membranes, proteins, and DNA, and may lead to chronic diseases, such as cancer, cardiovascular diseases, or neurodegenerative disorders (Shah M, 2020).

Heavy metals, such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and mercury (Hg) enter the environment due to atmospheric dispersion and deposition of harmful substances contaminating the air and ecosystems. The main sources of pollution include thermal power plants, electronics and automobile manufacturing, excessive use of agrochemicals, as well as improper disposal of industrial and household waste, contributing to soil and water pollution (Kanwar, 2020).

Effective and reliable detection of heavy metals in environmental water is crucial. In a study (Tokatli, 2019; Waqar, 2021), cluster analysis (CA) was used to classify the elemental composition of water resources in various settlements, and the weighted arithmetic water quality index was applied to evaluate the overall water condition. The study results showed that the greatest threat to drinking water quality comes from elements in the following descending order of risk: Se > As > Mo > B > Ba > Cr > Pb > Mn > Ni > Cd > Cu.

37 elements were identified in samples of tap and bottled water (Chowdhury, 2021), using inductively coupled plasma optical emission spectrometry (ICP-OES). The main goal was to assess the concentration of various elements in the water and their compliance with established standards. The concentrations of phosphorus (P), silicon (Si), fluorine (F), and chlorides (Cl) were within permissible levels of pollutants. Additionally, levels of elements such as aluminum (Al), boron (B), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lithium (Li), manganese (Mn), nickel (Ni), titanium (Ti), vanadium (V), and zinc (Zn) did not exceed the limits set by government agencies. However, heavy metals, including arsenic (As), cadmium (Cd), cobalt (Co), lead (Pb), mercury (Hg), and silver (Ag), were detected in the tap water of urban districts, indicating higher concentrations of pollutants in

urban areas compared to rural districts. Despite this, the levels of heavy metals remained below the maximum permissible concentrations ($P < 0.05$), indicating the safety of the water for consumption.

Inductively coupled plasma mass spectrometry (ICP-MS) is an extremely effective technique for quantifying heavy metals in water. This method is distinguished by its high sensitivity, precision, and reliability, making it ideal for environmental monitoring and water quality control. The reliability of ICP-MS in detecting trace concentrations of heavy metals is confirmed by the optimization of sample preparation methods and the analytical evaluation of performance indicators. Further research should focus on improving sample introduction techniques and addressing matrix interference issues to enhance the applicability of ICP-MS in various environmental conditions (Abdallah, 2023; Peng, 2015).

The ICP method, included in several standards such as DSTU and U.S. regulations, holds particular significance for determining concentrations due to its high sensitivity, accuracy, and capability to simultaneously determine multiple elements. Therefore, permanent monitoring and the use of advanced water purification methods are critical to preventing the accumulation of these hazardous metals in water supplies and ensuring public health.

Materials and Methods. The research was conducted at the Ukrainian Laboratory of Quality and Safety of Agricultural Products at the National University of Life and Environmental Sciences of Ukraine (NUBiP), accredited according to DSTU ISO/IEC 17025. Inductively coupled plasma atomic emission spectrometry (ICP-AES) is one of the modern methods applied for the qualitative and quantitative assessment of chemical elements, particularly heavy metals. This method is known for its high sensitivity, providing precise results due to its high resolution and minimal analyte loss, as well as enabling rapid analysis and near real-time data acquisition.

Sample preparation for determining the elemental composition of water was carried out according to the DSTU ISO 11885:2005 (ISO 11885:1996, IDT) standard "Water quality. Determination of 33 elements by inductively coupled plasma atomic emission spectrometry." The elemental composition of water samples was analyzed using an inductively coupled plasma atomic emission spectrophotometer, with the detection limit 0.01 mg/dm³ for most elements. Calibration of the equipment was performed using a multi-element standard solution IV from Merck KGaA, Germany, ensuring high accuracy of the results.

Results and Discussion. The aim of this study was to examine the elemental composition of water samples from water bodies in the Kyiv region. The water samples were filtered through membrane filters to remove suspended particles. The filtered samples underwent acid dissolution by concentrated nitric acid to ensure complete dissolution of elements. The determination of the content of elements in the water samples was performed using the ICP-AES method. The study examined the content of elements (Ag, Al, B, Ba, Bi, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Ni, Pb, Sr, Tl, Zn, Be, Mo, Se, Ti, V, As, Hg, S, P) in water samples to assess pollution levels and ensure environmental safety. Calibration solutions were prepared by sequential dilution of a multi-element standard solution. The obtained spectra were analyzed using software that compared signal intensities with the calibration curve to determine element concentrations in the samples.

The following conclusions can be done based on the analysis of the elemental composition of water (Table 1). The concentrations of heavy metals in

Table 1

Results of elemental analysis of water samples from Kyiv region, region F

Chemical element	Mass fraction, mg/dm³	Extended uncertainty	Detection limit, mg/dm³
Calcium, Ca	49,98	±10,09	0,01
Sodium, Na	25,15	±5,14	0,01
Magnesium, Mg	19,36	±4,09	0,01
Potassium, K	13,84	±3,07	0,01
Iron, Fe	1,63	±0,48	0,01
Strontium, Sr	0,49	±0,15	0,01
Zinc, Zn	0,14	±0,11	0,01
Manganese, Mn	0,17	±0,05	0,01
Boron, B	0,10	±0,06	0,01
Lithium, Li	0,07	±0,01	0,01
Aluminum, Al	0,06	±0,01	0,01
Barium, Ba	0,06	±0,01	0,01
Chromium, Cr	<0,01000	–	0,01
Lead, Pb	<0,01000	–	0,01
Copper, Cu	<0,01000	–	0,01
Nickel, Ni	<0,01000	–	0,01
Cobalt, Co	<0,01000	–	0,01
Silver, Ag	<0,01000	–	0,01
Bismuth, Bi	<0,01000	–	0,01
Molybdenum, Mo	<0,01000	–	0,01
Cadmium, Cd	<0,00100	–	0,001
Arsenic, As	<0,00100	–	0,001
Selenium, Se	<0,00100		0,001
Mercury, Hg	<0,00050		0,0005

the studied water samples are insignificant, indicating the safety of their levels. The detected values are within permissible limits, ensuring no risk of water contamination by metal ions. The content of nickel (Ni), cobalt (Co), copper (Cu), zinc (Zn), and manganese (Mn) in the water samples is very low. These low concentrations further confirm the high quality of the water and its compliance with regulatory standards. Thus, it can be concluded that the levels of heavy metals in the water are safe, and the water quality corresponds established standards.

It was determined that the concentrations of cobalt (Co), cadmium (Cd), lead (Pb), nickel (Ni), chromium (Cr), copper (Cu), and arsenic (As) are within acceptable limits or detected in trace amounts based on the results of the elemental water analysis presented in Table 2. This indicates that these metals are present in the water at safe levels, not exceeding regulatory values. Results of laboratory analysis showed that the water samples contain low concentrations of microelements. The concentrations of copper (Cu) and zinc (Zn) are 0.01 mg/dm^3, and manganese (Mn) is 0.011 mg/dm^3, all of which comply with standards. The levels of molybdenum (Mo), cadmium (Cd), arsenic (As), and bismuth (Bi) in the water are below 0.01 mg/dm^3, which is a positive indicator of water quality. The concentration of mercury (Hg) was found to be less than 0.005 mg/dm^3, meeting established standards and posing no risk to water resources. This analysis demonstrates that the concentrations of toxic metals in the samples were either below detection limits or very low, indicating no significant contamination.

Based on the comparative analysis of the elemental composition of water samples presented in Table 3, the following conclusions can be made regarding the content of heavy metals, cobalt (Co), cadmium (Cd), lead (Pb), nickel (Ni), chromium (Cr), and copper (Cu). The concentrations of these elements in the water samples are insignificant. This indicates that the levels of these metal ions in the water are permissible and do not exceed regulatory

Table 2

Results of elemental analysis of water samples from the Kyiv region, region H

Chemical element	Mass fraction, mg/dm^3	Extended uncertainty	Detection limit, mg/dm^3
Calcium, Ca	31,43	±4,20	0,01
Magnesium, Mg	11,52	±2,00	0,01
Sodium, Na	21,04	±3,71	0,01
Iron, Fe	0,07	±0,03	0,01
Potassium, K	6,15	±1,45	0,01
Strontium, Sr	0,25	±0,06	0,01
Barium, Ba	0,05	±0,04	0,01
Boron, B	0,08	±0,02	0,01
Lithium, Li	0,05	±0,01	0,01
Manganese, Mn	0,011	±0,005	0,01
Aluminum, Al	<0,010	–	0,01
Zinc, Zn	<0,01000	–	0,01
Chromium, Cr	<0,01000	–	0,01
Lead, Pb	<0,01000	–	0,01
Copper, Cu	<0,01000	–	0,01
Nickel, Ni	<0,01000	–	0,01
Cobalt, Co	<0,01000	–	0,01
Silver, Ag	<0,01000	–	0,001
Bismuth, Bi	<0,01000	–	0,01
Molybdenum, Mo	<0,01000	–	0,01
Cadmium, Cd	<0,001000	–	0,001
Arsenic, As	<0,001000	–	0,001
Selenium, Se	<0,001000		0,001
Mercury, Hg	<0,00050	–	0,0005

Table 3

Results of elemental analysis of water samples from Kyiv region, region N

Chemical element	Mass fraction, mg/dm^3	Extended uncertainty	Detection limit, mg/dm^3
Calcium, Ca	29,22	±6,25	0,01
Sodium, Na	21,21	±4,11	0,01
Magnesium, Mg	13,96	±2,90	0,01
Iron, Fe	0,06	±0,06	0,01
Potassium, K	6,88	±1,34	0,01
Strontium, Sr	0,18	±0,04	0,01
Boron, B	0,08	±0,04	0,01
Barium, Ba	0,05	±0,01	0,01
Lithium, Li	0,05	±0,01	0,01
Manganese, Mn	0,015	±0,005	0,01
Aluminum, Al	<0,01000	–	0,01
Zinc, Zn	<0,01000	–	0,01
Chromium, Cr	<0,01000	–	0,01
Lead, Pb	<0,01000	–	0,01
Copper, Cu	<0,01000	–	0,01
Nickel, Ni	<0,01000	–	0,01
Cobalt, Co	<0,01000	–	0,01
Silver, Ag	<0,01000	–	0,001
Bismuth, Bi	<0,01000	–	0,01
Molybdenum, Mo	<0,01000	–	0,01
Cadmium, Cd	<0,0010	–	0,001
Arsenic, As	<0,0010	–	0,001
Selenium, Se	<0,0010	–	0,001
Mercury, Hg	<0,00050	–	0,0005

limits. The concentrations of copper (Cu), zinc (Zn), and manganese (Mn) are sufficiently low, and vary within no more than 0.011 mg/dm³. The presence of these microelements in the water does not exceed allowable levels. The content of molybdenum (Mo), arsenic (As), bismuth (Bi), and mercury (Hg) also falls within acceptable limits, indicating no significant contamination by these metals. Overall, the concentrations of toxic metals were either very low or undetected, indicating their minimal presence in the samples.

Conclusions. The results of the elemental composition analysis of water indicate the absence of significant heavy metal contamination in the water bodies of the Kyiv region. The concentrations of elements, such as cobalt, cadmium, lead, nickel, chromium, copper, zinc, manganese, molybdenum, arsenic, bismuth, and mercury are within permissible limits, indicating a stable ecological condition of the region's water resources. The water is suitable for use without the need for immediate measures to reduce the concentrations of these metals. However, further research and regular monitoring are essential to maintain ecosystem stability and protect public health. The data from this study will serve as the basis for further water quality control measures, contributing to its safety and suitability for all types of use.

ЛІТЕРАТУРА:

1. Abdallah O., Khalid B. Quantitative determination of heavy metals in water using ICP-MS . *International Journal of Advanced Chemistry Research*. 2023. T.5. №1. C.115–116. https://doi.org/10.33545/26646781.2023.v5.i1b.192.

2. Chowdhury A.I., Kaur R., Akuley-Amenyenu A., Ikem A., Dennis S. Spectrochemical Analysis of Bottled and Tap Water from Selected Counties of Middle Tennessee, USA. *Journal of Water Resource and Protection*. 2021. T. 13. C. 20 – 31. https://doi.org/10.4236/jwarp.2021.131002.

3. Kanwar V.S., Sharma A., Lal S.A., Rani L. Phytoremediation of toxic metals present in soil and water environment: A critical review. *Environmental Science and Pollution Research*. 2020. T. 27. C. 44835–44860. https://doi.org/10.1007/s11356-020-10713-3.

4. Peng G., He Q., Zhou G., Li Y., Su X., Liu M., Fan L. Determination of heavy metals in water samples using dual-cloud point extraction coupled with inductively coupled plasma mass spectrometry. *Analytical Methods*. 2015. T. 7. C. 6732. https://doi.org/10.1039/c5ay00801h.

5. Shah M., Suleman M., Samiullah A.B., Sattar A., Khan N., Rehman A. Determination of heavy metals in drinking water and their adverse effects on human health: A review. *Pure and Applied Biology (PAB)*. 2020. T. 9. № 1. C. 96 – 104. https://doi.org/10.19045/bspab.2020.90012.

6. Tokatli C. Drinking Water Quality Assessment of Ergene River Basin by Water Quality Index: Essential and Toxic Elements . *Sains Malaysiana*. 2019. T. 48. № 10. C. 2071 – 2081. https://doi.org/10.17576/jsm-2019-4810-02.

7. Waqar A., Alharthy R.D., Zubair M., Ahmed M., Hameed A., Rafque S. Toxic and heavy metals contamination assessment in soil and water to evaluate human health risk. *Scientific Reports*. 2021. T. 11. C. 17006. https://doi.org/10.1038/s41598-021-94616-4.

8. ДСТУ EN ISO 17294-2:2019. *Якість води. Використання мас-спектрометрії з індуктивно-зв'язаною плазмою (ІЗП-МС). Частина 2. Визначення 62 елементів* (EN ISO 17294-2:2016, IDT; ISO 17294-2:2016, IDT). Київ: ДП «УкрНДНЦ», 2019. 40 с.

9. ДСТУ ISO 17294-1:2015. *Якість води. Застосування мас-спектрометрії з індуктивно-зв'язаною плазмою (ICP-MS). Частина 1. Загальні настанови* (ISO 17294-1:2004, IDT). Київ: ДП «УкрНДНЦ», 2015. 24 с.

10. ASTM D5673-16. *Standard Test Method for Elements in Water by Inductively Coupled Plasma – Mass Spectrometry*. West Conshohocken, PA: ASTM International. 2016. 10 c.

REFERENCES:

1. Abdallah, O., & Khalid, B. (2023). Quantitative determination of heavy metals in water using ICP-MS. *International Journal of Advanced Chemistry Research*, 5(1), 115–116. https://doi.org/10.33545/26646781.2023.v5.i1b.192.

2. Chowdhury, A.I., Kaur, R., Akuley-Amenyenu, A., Ikem, A., & Dennis, S.O. (2021). Spectrochemical analysis of bottled and tap water from selected counties of Middle Tennessee, USA. *Journal of Water Resource and Protection, 13*(1), 20 – 31. https://doi.org/10.4236/jwarp.2021.131002

3. Kanwar, V.S., Sharma, A., Lal, S.A., & Rani, L. (2020). Phytoremediation of toxic metals present in soil and water environment: A critical review. *Environmental Science and Pollution Research*, 27, 44835–44860. https://doi.org/10.1007/s11356-020-10713-3.

4. Peng, G., He, Q., Zhou, G., Li, Y., Su, X., Liu, M., & Fan, L. (2015). Determination of heavy metals in water samples using dual-cloud point extraction coupled with inductively coupled plasma mass spectrometry. *Analytical Methods*, 7, 6732. https://doi.org/10.1039/c5ay00801h.

5. Shah, M., Suleman, M., Samiullah, A. B., Sattar, A., Khan, N., & Rehman, A. (2020). Determination of heavy metals in drinking water and their adverse effects on human health: A review. *Pure and Applied Biology (PAB)*, 9(1), 96 – 104. https://doi.org/10.19045/bspab.2020.90012.

6. Tokatli, C. (2019). Drinking water quality assessment of Ergene River Basin by Water Quality Index: Essential and toxic elements. *Sains Malaysiana*, 48(10), 2071 – 2081. https://doi.org/10.17576/jsm-2019-4810-02.

7. Waqar, A., Alharthy, R. D., Zubair, M., Ahmed, M., Hameed, A., & Rafque, S. (2021). Toxic and heavy metals contamination assessment in soil and water to evaluate human health risk. *Scientific Reports*, 11, 17006. https://doi.org/10.1038/s41598-021-94616-4.

8. DSTU EN ISO 17294-2:2019. (2019). *Yakist vody. Vykorystannia mas-spektrometriyi z induktyvno-zv'iazanoiu plazmoiu (IZP-MS). Chastyna 2. Vyznachennia 62 elementiv* [Water quality. Application of inductively coupled plasma mass spectrometry (ICP-MS). Part 2. Determination of 62 elements]. Kyiv: DP "UkrNDNC" [in Ukrainian].

9. DSTU ISO 17294-1:2015. (2015). *Yakist vody. Zastosuvannia mas-spektrometriyi z induktyvno-zv'iazanoiu plazmoiu (ICP-MS). Chastyna 1. Zahalni nastanovy* [Water quality. Application of inductively coupled plasma mass spectrometry (ICP-MS). Part 1. General guidelines]. Kyiv: DP "UkrNDNC" [in Ukrainian].

10. ASTM D5673-16. (2016). *Standard test method for elements in water by inductively coupled plasma - mass spectrometry*. West Conshohocken, PA: ASTM International.