ECOLOGICAL AND HYGIENIC MONITORING OF LITHIUM IN WATERS FOR VARIOUS PURPOSES IN UKRAINE AND APPROACHES TO POST-TREATMENT

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The technological revolution is transforming global demand for resources, shifting the focus from traditional energy sources like oil and gas to metals such as lithium, cobalt, and nickel. Lithium, now dubbed "white oil", is critical for powering devices and vehicles, as lithium-ion batteries are foundational in consumer electronics and electric vehicles. Historically, lithium's primary application was in the glass and ceramics industries, with secondary uses in optics and electronics. However, demand has increased substantially in recent years due to advancements in energy storage technology. The environmental impacts of lithium extraction are significant, raising levels of heavy metals like arsenic in nearby surface waters. Traditional extraction methods create evaporation ponds that lead to environmental risks, potentially releasing lithium and other metals into the ecosystem. Environmental monitoring has shown elevated lithium concentrations in contaminated industrial sites and mining runoff areas, often exceeding safe drinking water limits. Current U.S. guidelines from the EPA focus on safe recycling practices for lithium-ion batteries, but regulatory frameworks are lacking in other regions, including Ukraine. In Europe, lithium battery producers are required to incorporate recycling costs into their products, with Germany opening a lithium processing facility to support local demand and decrease reliance on imports. In Ukraine, significant lithium reserves exist, potentially among the largest in Europe, though official regulation for lithium energy storage management is lacking. Given lithium's toxic effects at high doses — such as impacts on the gastrointestinal tract, kidneys, and nervous system — further environmental monitoring and risk assessment are crucial for sustainable development and public health protection.

Keywords: *lithium; electronic waste; environmental pollution; monitoring; purification; toxicity*

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1. Introduction

The technological revolution is gradually altering the structure of resource demand. The necessity for oil and gas is diminishing, while the demand for lithium, cobalt, nickel, and other metals utilized in gadgets, electric vehicles, solar panels, and other technologies is increasing. Lithium, also referred to as "white oil", has gained prominence, underscoring its significance. This metal is utilised in the production of batteries for a range of electronic devices, including smartphones, computers, power tools and electric vehicle engines.

For a considerable length of time in history, lithium ores were predominantly employed in the manufacture of glass, glass ceramics, porcelain enamels, fritted glazes, refractory materials, batteries, lubricants, and a plethora of other products. The glass-ceramics industry continues to represent a significant consumer of lithium. Furthermore, lithium is a crucial component in the field of specialised optics, where it is employed in metal insulating films for glass, incorporated into the composition of prospective glass lenses, and manufactured into monocrystalline lithium fluoride lenses, which exhibit superior transparency to UV radiation compared to alternative materials (Kavanagh, L., 2018; Hoskinson, Carolyn, 2023; EPA. Lithium in Drinking Water, 2023).

Over the past 15 years, global lithium consumption for lithium chemical power sources (CPS) has also increased. It is established that approximately a quarter to half of all known reserves have been extracted. The demand for lithium CPS has increased in recent years, driven by the growing needs of the consumer electronics and electric vehicle production sectors. Lithium is also utilised in the manufacture of weaponry, including ballistic missiles, and in the production of batteries for unmanned aerial vehicles. The production of drones has increased markedly since the outbreak of hostilities in Ukraine. It is of paramount importance to select the appropriate batteries for FPV drones in order to achieve optimal performance and flight duration. The current market for drones comprises three principal types of lithium battery: lithium-polymer (Li-Po), lithium-ion, lithium iron phosphate ($LiFePO_4$), and lithium-titanate (LiTiO).

It has been demonstrated that the extraction of lithium can result in an increase in the concentration of other heavy metals, such as arsenic, in the surrounding surface waters (Povyakel, L. I., 2015; Kavanagh, L., 2018; Hoskinson, Carolyn, 2023). In the conventional method of lithium extraction, salt-rich brine is extracted from subterranean depths and transported to the surface, where it is concentrated to create artificial lakes that subsequently evaporate (Andrusyshyna, I. M., 2022). Lithium can also be extracted from hard ores. In light of the techniques employed in lithium extraction, it is reasonable to posit a considerable risk of environmental contamination, which could result in the toxicity of lithium and other metals, including lead, cadmium, copper, silver, gold, and palladium (Povyakel, L. I., 2015; Andrusyshyna, I. M., 2022).

Lithium compounds have been demonstrated to elicit pronounced irritant effects. The primary effects of these compounds are observed in the gastrointestinal tract, kidneys, and central nervous system. Additionally, they exhibit cholinomimetic effects, elevate serotonin levels in the brain, and influence carbohydrate metabolism and cellular respiration. Lithium functions as a biological antagonist of sodium and is particularly toxic when the diet is deficient in sodium. Exposure to lithium has been associated with an increased risk of impaired kidney function, hypothyroidism, hyperparathyroidism, and weight gain (Andrusyshyna, I. M., 2022; Brown, C. W., 2024; Adeel, M, 2023). The administration of high doses of lithium as a pharmacological agent has been associated with a range of adverse effects, including general weakness, loss of appetite, thirst, dry mouth (sometimes accompanied by salivation), nausea, vomiting, diarrhea (characterized by its watery or bloody nature), tremors (present in the lips, jaw, and hands), dizziness, vision disturbances, drowsiness, and slowed speech. The safe range for lithium blood levels is 4.1 to 8.3 mg/L. Toxicity is observed when the concentration level reaches 10.4 mg/L or higher. Severe lithium toxicity is observed at levels of 13.9 mg/L and above, which, in rare cases, can be life-threatening. Levels of 20 mg/L or above are regarded as critical and necessitate immediate medical intervention (Andrusyshyna, I. M., 2022).

While lithium is present in minerals and various rock types, different clays have the capacity to accumulate minute quantities of Li^+ cations, particularly when pH levels are elevated. Furthermore, surface waters in areas with technogenic pollution may also exhibit elevated lithium levels. For example, the discharge of substantial volumes of mine wastewater into the Donbas river basin (Ukraine) ecosystem has resulted in lithium levels of 11.8 to 13.7 mg/L being recorded as of 2014.

The maximum permissible concentration of lithium in drinking water in Ukraine is set at a maximum of 0.03 mg/L (Ministry of Health of Ukraine, 2022), although this value does not always meet the standard. It has been reported by experts that bottled drinking water, whether processed or natural mineral water from springs, often contains significantly higher lithium levels than tap water (Ministry of Health of Ukraine, 2022; Antomonov, M. Y., 2017). The physiological limit of lithium in water is defined as 90–200 µg, while an intake of 200 mg of lithium is considered to be toxic.

It is a verifiable fact that Ukraine possesses considerable lithium deposits, which are likely to be the largest in Europe. However, estimates range from 500 thousand tons, which would be a considerable asset, to 5 million tons, which would be highly beneficial, comparable to reserves in leading countries (Argentina, Chile, Bolivia, China, Australia, with notable reserves also in the United States, Canada, and Congo). Global lithium reserves are estimated to exceed 50 million tons, although this figure is also an estimate and may be considerably higher. No official documents regulating the handling of lithium chemical power sources exist in Ukraine. It is only known that lithium chloride is included in the list of substances for which emission fines are established.

It is anticipated that significant environmental contamination from lithium will occur in Ukraine in the near future. However, there is currently no monitoring of lithium pollution in the environment, particularly in water bodies. Some literature sources and reports from the United States Environmental Protection Agency (EPA) indicate that lithium, like per- and polyfluoroalkyl substances (PFAS), is a potential pollutant and a candidate for inclusion on the list of hazardous substances (Hoskinson, Carolyn, 2023; EPA. Lithium in Drinking Water, 2023; Lombard, M. A., 2024).

The maximum allowable concentration (Maximum Permissible Concentration - MPC) for lithium in the drinking water regulation DSanPiN 2.2.4.-171-10 (DSanPiN 2.2.4-171-10, 2010), which pertains to the quality of water supplied and collected, is absent. In DSTU 4808-2007 (DSTU 4808:2007, 2007), the regulation of water quality is conducted according to defined classes. The permissible concentrations of lithium are as follows: Class 1: 0.01 mg/L, Class 2: 0.01-0.02 mg/L, Class 3: 21-50 µg/L, and Class 4: greater than 100 µg/L. The hygienic standards approved by the Ministry of Health in 2022 set the permissible concentration at 0.03 mg/dm³ (Ministry of Health of Ukraine, 2022).

The aim of this work was to present the results of pilot monitoring of lithium content in natural and drinking waters of Ukraine in 2020-2024 and to study the possibilities of using synthetic and natural sorbents to remove lithium from model aqueous solutions.

2. Materials and Methods

Research was conducted to study the lithium content in 300 samples of drinking water and water from surface and groundwater sources in the Kyiv region and some regions of Ukraine (2020-2024). Water samples were taken in accordance with the requirements of DSTU ISO 5667-11:2005 "Drinking water. Water sampling" (DSTU ISO 5667-11:2005, 2005). The lithium content in water was determined using the method of inductively coupled plasma optical emission spectroscopy (ICP-OES) on the Optima 2100 DV device by Perkin-Elmer (USA) according to the method given in DSTU ISO 11885-2019 (DSTU ISO 11885:2019, 2019). To calibrate the device, an ICP-multi-element standard solution containing 23 chemical elements No. 111355,0100 (Germany), including lithium at a concentration of 1000 mg/L, was used. The lithium content was analyzed in the axial plasma mode. The limit of detection (LOD) of lithium at a wavelength of 670.784 nm in water was 0.0006 mg/L.

The sorption properties of various sorbents (amberlite, zeolite, cationite, mycotone, and pectin) for the removal of excess lithium in water were also studied. For this purpose, 3 different concentrations of lithium in tap water (0.063, 0.62, and 1.20 mg/L) were used and 0.1 g of sorbent was added. The total volume of the solutions for each individual sample was 10 ml, and after thorough mixing (20 min), the supernatant was separated and the lithium content in the solution was analyzed by the OEC-ICP method To ensure accuracy, the measurement was repeated twice. In this regard, the experimental value was considered accurate if the relative standard deviation did not exceed 2%. The mathematical processing of the results was performed using the software of the OES-ISP WinLab32 device, the statistical processing was performed using the Microsoft Excel software package according to the following formulas (Antomonov, M. Y., 2017).

3. Results and Discussion

Due to the increasing exposure to lithium in natural and drinking water resulting from the growing use of lithium-ion batteries in various gadgets (mobile phones, computers, etc.), vehicles, and drones, there is a rising need to monitor its content in drinking water.

The regulatory standards for lithium in drinking water vary by organization and region. Here's a summary based on EPA, WHO, and EU guidelines:

EPA (United States):

The EPA does not currently have a specific Maximum Contaminant Level (MCL) for lithium in drinking water. However, lithium is considered a "contaminant of emerging concern", and it has been added to the EPA's Contaminant Candidate List for future monitoring and potential regulation (WHO. Guidelines for Drinking-Water Quality, 2011).

WHO (World Health Organization):

The WHO does not provide a specific guideline value for lithium in drinking water in its standard recommendations. However, it recognizes the need to monitor lithium due to its increasing prevalence in water sources. WHO guidance focuses on ensuring water safety while considering the broader context of chemical exposure from environmental and industrial sources (EPA. Contaminants of Emerging Concern—Lithium, 2020).

EU (European Union):

The EU Drinking Water Directive (2020/2184), which sets out parameters for drinking water quality, does not specifically list lithium. However, it emphasizes a risk-based "source-to-tap" approach to ensure safety and mentions the addition of emerging substances to a watch list for further evaluation. Lithium could be included in future assessments as a contaminant requiring monitoring (European Union. Drinking Water Directive (2020/2184), 2020; REHVA. The New EU Drinking Water Directive, 2021).

As mentioned above, Ukraine has an appropriate regulatory framework (DSTU 4808:2007, 2007; Ministry of Health of Ukraine, 2022). Thus, the first stage of this research involved analyzing the results of monitoring lithium levels in various drinking water sources during 2022-2024. The obtained monitoring results for lithium content in different types of water are presented in Table 1.

Table 1. *Lithium content depending on the type of water source in Ukraine (2024)*

Water Type	**Concentration Range (µg/dm³)**	**Average ± Standard Error (M ± m)**	**Regulations (Maximum Permissible Concentration) (µg/L)**
Tap water	1.0 - 6.0	5.0 ± 0.10	30
Artesian water	10.0 - 110	6.0 ± 0.12	10 - 20
Well water	12.0 - 82.0	**46.0 ± 0.92**	10 - 20
Natural water (rivers, lakes)	11.0 - 770.0	**39.0 ± 0.78**	10 - 20
Spring water	3.6 - 16.0	9.80 ± 0.20	10 - 20
Rainwater	1.0 - 2.0	1.5 ± 0.03	Not regulated

Note: Classification of surface water quality — sources for centralized drinking water supply:

- Class 1: Less than 10 µg/L
- Class 2: 10–20 µg/L
- Class 3: 21–50 µg/L
- Class 4: More than 100 µg/L

Classification of groundwater quality — sources for centralized drinking water supply:

- Class 1: Less than 10 µg/L
- Class 2: 10–20 µg/L
- Class 3: 21–50 µg/L
- Class 4: More than 100 µg/L

We also have up-to-date data on the presence of lithium at tap water in different regions of Ukraine (Table 2).

Table 2. *Lithium content in tap water in different regions of Ukraine (data from 2022-2024)*

Sampling location, region	Number of samples	Lithium content, μg/L	DSTU 4808-2007 (for water sources of class 2), μg/L
Kyiv	12	1.0 - 5.0	10 - 20
Dnipropetrovsk	7	1.0 - 6.0	
Mykolaiv	5	1.0 - 3.20	
Lviv	12	2.0 - **30.0**	
Donetsk	14	1.0 - 3.80	
Zaporizhzhya	6	1.0 - 3.40	
Ternopil	10	0.6 - 10.0	
Odesa	5	1.0 - 18.0	

Note: taking into account the gross content of all forms of lithium

The lithium content in various sources of surface and groundwater used for drinking purposes is shown in Figure 1. In surface drinking water sources, lithium levels exceeding the limits for Class 2 sources, as per DSTU 4808-2007, were identified, indicating contamination by this metal.

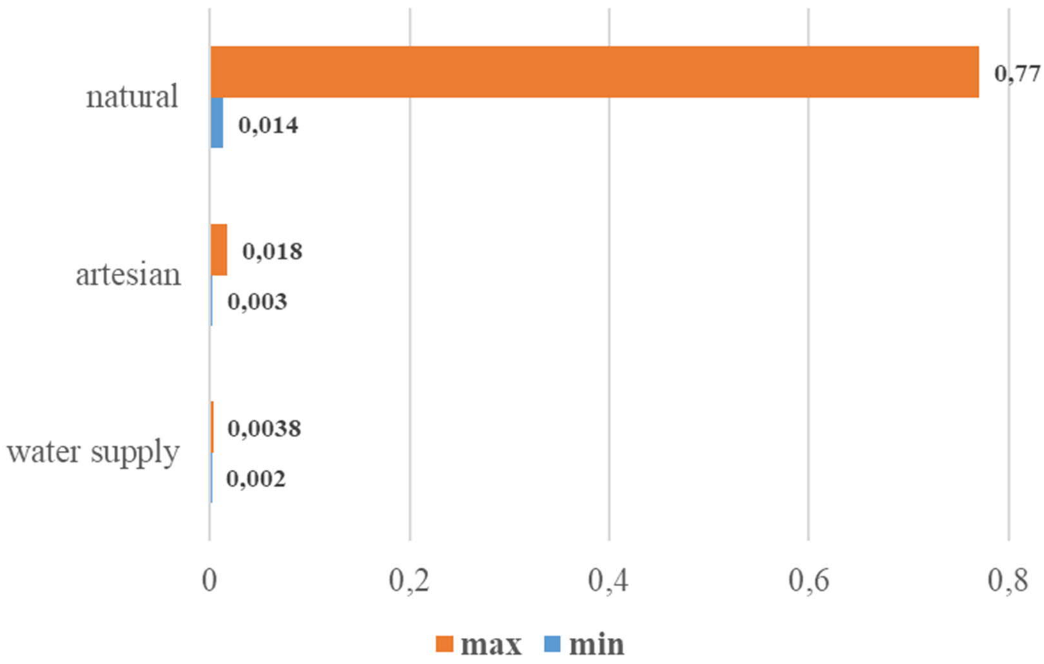

Fig. 1. *Lithium content in different types of water sources in Kyiv city, mg/L (min-max)*

The results of the monitoring of lithium content in natural water bodies conducted between 2020 and 2024 are presented in Figure 2.

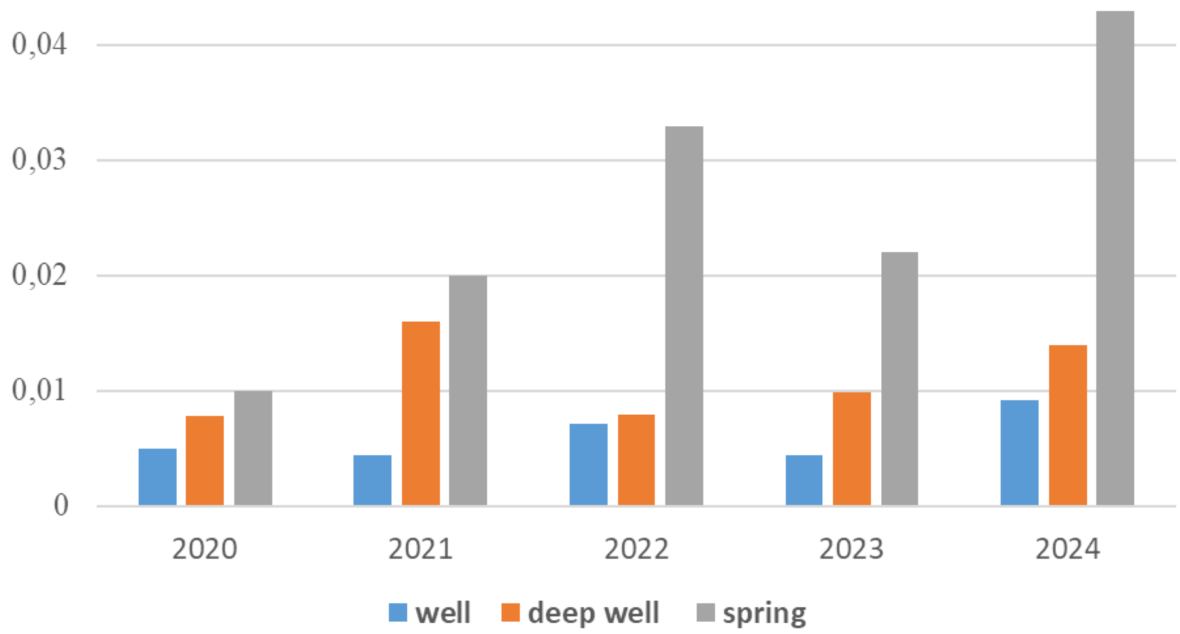

Fig. 2. *Monitoring of lithium content in surface and groundwater bodies in Ukraine in the period 2020-2024*

Figure 2 illustrates that the optimal detection of lithium content is in natural groundwater and surface water bodies (data from the Kyiv, Zhytomyr, and Ternopil regions) in comparison to centralized water supply sources. In accordance with the standards set forth in DSTU 4808-2007, the detected content can be attributed to water sources of class 3, which specifies a maximum permissible concentration of 0.03 mg/L. However, in certain instances, the detected concentration exceeded this threshold. The highest concentration was observed in spring water. A twofold increase was observed over the course of the period between 2022 and 2024.

It was determined that wastewater samples from Lviv exhibited concentrations of lithium that were 7.8 times higher than those observed in water samples from Kropyvnytskyi (Table 3). Furthermore, the concentration of lithium in the wastewater samples from Kharkiv was also considerable, with the lowest levels observed in Kyiv and Uzhhorod (the ratio of the maximum to the minimum value was 1.3).

Table 3. *Lithium content in Ukrainian wastewater depending on the sampling location*

Sampling location	Location	Lithium content, mg/L		
		min	max	average
Ternopil	West	0.0084	0.0119	0.0103
Uzhhorod	West	0.0062	0.0083	0.0069
Lviv	West	0.0129	0.0367	0.0175
Kropyvnytskyi	Centre	0.0051	0.0083	0.0062
Zaporizhzhia	Centre	0.0062	0.0087	0.0073
Cherkasy	Centre	0.0047	0.0073	0.0055
Kyiv	North	0.0071	0.0092	0.0084
Sumy	East	0.0083	0.0137	0.0122
Kharkiv	East	0.0055	0.0249	0.0138
Kherson	South	0.0133	0.0185	0.0162

The second stage of the research involved a comparative study of the absorption properties of sorbents, including Amberlite, zeolite, sorbent A-450, pectins, and Mycoton. The choice of these sorbents was not random.

Amberlite, a mono-ion exchange resin, is widely used in multi-stage water filtration systems. Its primary purpose is water softening, achieved by replacing calcium and magnesium ions with sodium ions. A notable advantage of this material is its cost-effectiveness.

Zeolite 545 is a large group of minerals composed of hydrated aluminosilicates of calcium and sodium, sometimes substituted by potassium (K), barium (Ba), strontium (Sr), and others. Synthetic zeolites, known as permutites, are used for water softening, purifying fats, oils, and juices. Zeolites function as adsorbents, ion exchangers, molecular sieves, and catalysts, with applications in cement production and as heterogeneous catalysts in petrochemical and petroleum refining processes.

Sorbent A-450, based on silicon dioxide, is a porous material derived from the silica shells of diatom algae.

Pectin is a complex ester of methyl alcohol and pectic acid. Its significant biological properties stem from the presence of free carboxyl and hydroxycarboxyl groups of galacturonic acid. These groups can bind heavy metals, including radionuclides, forming insoluble complexes that are excreted from the body.

Mycoton is a natural biosorbent derived from the fungus Fomes fomentarius (commonly known as tinder fungus). Its composition includes chitin, glucans, and melanin. It is the only natural biopolymer containing nitrogen atoms in its molecule, providing unique absorption properties, such as the ability to capture toxins and heavy metals (e.g., Pb, As).

The results of model studies demonstrated that lower lithium concentrations in the solution led to better adsorption (Table 4). This trend was particularly evident for zeolite and sorbent A-450. Natural sorbents, such as pectin and Mycoton, which are commonly used in toxicology, also proved effective in removing lithium from model aqueous solutions. This suggests their potential application beyond scientific research.

Table 4. Comparative evaluation of different sorbents for the removal of lithium from tap water

Sorbent type	Lithium content, mg/L		Removal efficiency, %
	entered	found	
Amberlite	0.06	0.032	53.33
	0.63	0.23	36.51
	1.20	0.60	50.0
Zeolite 545	0.06	0.041	68.33
	0.63	0.20	31.75
	1.20	0.80	66.67
Sorbent A-450	0.06	0.045	75.0
	0.63	0.30	47.62
	1.20	0.61	50.83
Pectin	0.06	0.051	85.0
	0.63	0.26	41.27
	1.20	0.61	50.83
Mycoton	0.06	0.056	93.33
	0.63	0.42	66.67
	1.20	0.83	69.17

Thus, the conducted studies indicate that natural waters may contain significant concentrations of lithium. This contamination could result in environmental accumulation due to the increasing presence of lithium in electronic and other household waste. The use of both traditional and natural sorbents shows promise for treating water intended for human consumption.

4. Conclusions

The study provides comprehensive insights into the increasing environmental and health risks associated with lithium contamination in natural and drinking water. The findings highlight the criticality of monitoring lithium levels, especially considering its growing demand in electronic devices, electric vehicles, and drones. Key conclusions from the research are as follows:

Lithium Contamination Trends:

Lithium concentrations in water sources in Ukraine vary widely, often exceeding permissible levels set by national regulations. Notably, well water and natural water bodies, such as rivers and lakes, were most prone to higher lithium contamination.

The rise in lithium pollution correlates with increased use and improper disposal of lithium-ion batteries and electronic waste.

Health Implications:

Elevated lithium exposure poses significant health risks, including kidney dysfunction, thyroid disorders, and neurological effects. The study underscores the need to adhere to safe lithium concentration thresholds in drinking water.

Effectiveness of Sorbents:

The experimental phase demonstrated that both synthetic (Amberlite, zeolite, A-450) and natural (pectin, Mycoton) sorbents effectively reduce lithium levels in water.

Among the tested sorbents, natural materials like Mycoton and pectin showed superior adsorption capabilities, with Mycoton achieving over 93% removal efficiency at low lithium concentrations.

Policy and Monitoring Gaps:

Current regulations in Ukraine and globally are inadequate for managing lithium as an emerging contaminant. The absence of a specific Maximum Contaminant Level (MCL) for lithium in many international and national frameworks reflects a regulatory gap.

Recommendations:

The integration of effective sorbents in water treatment systems could offer a viable solution for lithium removal, ensuring safer drinking water.

Strengthening regulatory frameworks, conducting routine monitoring, and raising public awareness about lithium pollution are critical steps to mitigate its environmental and health impacts.

In conclusion, the study underscores the pressing need for proactive measures to manage lithium contamination. The adoption of advanced water treatment techniques and stricter regulatory standards will be crucial in safeguarding environmental and public health in the face of escalating lithium demand.

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ЕКОЛОГО-ГІГІЄНІЧНИЙ МОНІТОРИНГ ЛІТІЮ У ВОДАХ РІЗНОГО ПРИЗНАЧЕННЯ В УКРАЇНІ ТА ПІДХОДИ ДООЧИЩЕННЯ

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Технологічна революція трансформує глобальний попит на ресурси, зміщуючи фокус з традиційних джерел енергії, таких як нафта і газ, на метали, такі як літій, кобальт і нікель. Літій, який зараз називають «білою нафтою», має вирішальне значення для живлення пристроїв і транспортних засобів, оскільки літій-іонні акумулятори є основою побутової електроніки та електромобілів. Історично склалося так, що літій в основному застосовувався у скляній та керамічній промисловості, а також в оптиці та електроніці. Однак в останні роки попит на нього значно зріс завдяки розвитку технологій зберігання енергії. Видобуток літію має значний вплив на навколишнє середовище, підвищуючи рівень важких металів, таких як миш'як, у прилеглих поверхневих водах. Традиційні методи видобутку створюють ставки-випаровувачі, які призводять до екологічних ризиків, потенційно вивільняючи літій та інші метали в екосистему. Моніторинг довкілля показав підвищену концентрацію літію на забруднених промислових майданчиках і в зонах стічних вод гірничодобувних підприємств, яка часто перевищує нормативи для безпечної питної води. Чинні керівні принципи Агентства з охорони навколишнього середовища США зосереджені на безпечній переробці літій-іонних акумуляторів, але в інших регіонах, зокрема в Україні, нормативно-правова база відсутня. У Європі виробники літієвих батарей зобов'язані включати витрати на переробку у вартість своєї продукції, а в Німеччині відкрили завод з переробки літію, щоб підтримати місцевий попит і зменшити залежність від імпорту. В Україні існують значні запаси літію, потенційно одні з найбільших у Європі, хоча офіційне регулювання управління літієвими накопичувачами енергії відсутнє. Враховуючи токсичні ефекти літію у високих дозах - наприклад, вплив на шлунково-кишковий тракт, нирки та нервову систему - подальший моніторинг довкілля та оцінка ризиків мають вирішальне значення для сталого розвитку та захисту здоров'я населення.

***Ключові слова**: літій; електронні відходи; забруднення навколишнього середовища; моніторинг; очищення; токсичність*