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SOIL CONTAMINATION WITH HEAVY METALS: A HYGIENIC CONCERN

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Introduction. Soil pollution commonly results from metals, organic wastes, oils, tar, pesticides, explosives, toxic residues, radioactive materials, and biologically active combustible substances. Sources of such pollution encompass industrial and domestic waste sites, as well as unauthorized disposal areas. Today, soil pollution in Ukraine reflects not only economic activities but also the consequences of ongoing military operations.

The aim of the research – is to analyze literature concerning heavy metal contamination of environmental elements resulting from warfare and its implications for public health.

Materials and мethods of the research. An analytical review of scientific publications was conducted using medical databases along with internet resources.

Results. Ukraine's recovery post-war entails overcoming extensive heavy metal contamination and addressing mining threats. Territorial scale and complexity necessitate long-term, resource-intensive recovery efforts. Comparative studies reveal complex contamination recovery challenges. Post-First World War France categorized war-damaged areas into green, yellow, and red zones. Balkan Peninsula countries face post-conflict ecological and institutional recovery hurdles. Post-war recovery challenges include coordination, data consolidation, and long-term toxicological monitoring. Pregnant women face increased risks from heavy metal exposure. Studies report livestock morbidity increases from mercury, lead, copper, magnesium, lithium, TNT, and depleted uranium soil and water contamination. Ukraine's post-war recovery challenges differ from traditional contexts, owing to ongoing conflict and extensive heavy metal contamination. Strategic recovery includes minimization of heavy metal exposure to vulnerable populations. The global community must step up efforts to address heavy metal contamination from military operations. Efforts must prioritize recovery of soil functionality to minimize heavy metal exposure risks.

Conclusions. Military activities cause extensive and prolonged environmental degradation, with contamination by heavy metals and toxic substances leading to significant economic, ecological, medical, and social impacts. Developing a recovery strategy for Ukraine must be specific to its circumstances and cannot solely rely on experiences from other countries due to ongoing pollution from active hostilities. After the war, a comprehensive research program focusing on military-induced environmental and public health effects should be prioritized.

Key words: soils, heavy metals, pollution, health risks

Introduction

The interplay between environmental quality and human health is a fundamental connection. According to WHO data, approximately 25% of global illnesses stem from adverse environmental conditions, and over 1 billion people reside in areas with significant air pollution [1]. Soil pollution commonly results from metals, organic wastes, oils, tar, pesticides, explosives, toxic residues, radioactive materials, and biologically active combustible substances. Sources of such pollution encompass industrial and domestic waste sites, as well as unauthorized disposal areas. Today, soil pollution in Ukraine reflects not only economic activities but also the consequences of ongoing military operations [2].

Heavy metals and their derivatives occupy an important position among the various contaminants. These metals, prevalent in industry and waste accumulation, pose significant risks to human health and the environment [3]. The problem of heavy metal contamination has escalated due to active military operations in Ukraine, resulting in the deposition of munitions and equipment remnants across agricultural lands, leading to alterations in soil composition following explosions [2]. The presence of hazardous metals like mercury, cadmium, lead, chromium, copper, zinc, and arsenic in soil poses a serious threat [4]. The accumulation of these metals in soil and food products can have toxic effects on the human body, affecting vital systems such as the central and peri-

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pheral nervous systems, hematopoiesis, endocrine functions, and metabolism [5]. Epidemiological monitoring of heavy metals and their health impacts is essential in Ukraine, particularly in the context of post-war recovery efforts.

The aim of the research – is to analyze and synthesize global and domestic literature concerning heavy metal contamination of environmental elements resulting from warfare and its implications for public health.

Materials and methods of the research

An analytical review of scientific publications was conducted using databases such as PubMed, MEDLINE, Free Medical Journals, BioMed Central, and the V. I. Vernadsky National Library of Ukraine, along with internet resources.

Results of the research and their discussion

1. Sources of Soil Contamination with Heavy Metals

Soils play crucial roles in terrestrial ecosystems, and their ecological and geochemical conditions are essential for the Earth's biosphere stability and human survival. Heavy metals enter soils from atmospheric deposition, surface runoff, subsoil minerals, and groundwater, with potential secondary contamination of water bodies. Plants assimilate these metals, which then enter the food chain, posing health risks to humans [6].

Natural soil pollution arises from the influx of heavy metals and their derivatives from parent rocks and deep ore deposits. Anthropogenic activities, such as industrial processes, significantly increase the influx of heavy metals into soils, leading to reduced crop yields and quality, as well as risks to human and animal health.

According to Ukrainian environmental services, approximately 1,800 tons of lead and 400 tons of cadmium are introduced into soils annually through pesticides and mineral fertilizers. Consequently, certain regions exhibit heavy metal concentrations 2–5 times higher than natural background levels, with metals persisting in soils for decades or even centuries [7]. Lead and cadmium contamination extends beyond industrial sites, affecting agricultural lands and food products, thus posing additional health risks through dietary exposure [8].

Plants, like all organisms, can tolerate increasing heavy metal concentrations up to a certain threshold. Beyond this threshold, heavy metals can suppress and kill organisms, leading to reduced species diversity and poor conditions for plant growth.

The distribution of heavy metals in soil is influenced by several factors [9]:

- soil texture: soil particle size directly impacts adsorption properties, with finer particles inhibiting metal transfer beyond the soil profile and promoting accumulation;
- oxides and hydroxides: iron, aluminum, and manganese oxides and hydroxides play pivotal roles in metal mobility in soil, affecting metal sorption through isomorphic substitution;
- soil pH: acidic soils facilitate the formation of soluble organo-mineral complexes by heavy metals;
- carbonate content: carbonates reduce metal mobility in soils by influencing environmental pH and sorption properties;
- fertilizer application: fertilizers alter soil pH, affecting microelement compound solubility, intensifying exchange reactions, and influencing metal accumulation;
- soil organic matter: organic matter acts as a metal inactivator, enhancing soil buffering capacity, reducing metal toxicity, and preventing plant uptake;
- soil biota: soil microbial activity influences the mobile forms of heavy metals over time, affecting chemical element absorption by plants;
- soil profile migration: heavy metals undergo various transformations within soil profiles, with mobility typically reduced by humus fixation. The uppermost soil layer often exhibits increased metal content due to migration and fixation processes.

An indicator used to classify soil pollution levels is the accumulation coefficient (AC), which represents the multiplication factor of average metal content in the soil. Uncontaminated soils typically have an AC value of 1–2. Soil pollution levels are categorized based on AC values: slightly polluted (up to 10 AC), moderately polluted (10–30 AC), heavily polluted (30–60 AC), and very heavily polluted (more than 60 AC). According to hygienic principles for assessing soil pollution, permissible heavy metal levels in soils are aligned with the criteria for heavily polluted soils.

In instances of multiple-element contamination, the total pollution index (TPI) is calculated to assess overall contamination severity. TPI-based ratings

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evaluate soil contamination risks and inform health assessments of affected populations as presented in Table.

The accumulation of heavy metals in soil and food products poses toxic risks to human health. Even at relatively low concentrations, heavy metals like lead, mercury, and cadmium exert membrane and cytotoxic effects, disrupt metabolic processes, and cause pathological changes in vital systems, including the central and peripheral nervous systems, hematopoiesis, endocrine functions, and metabolism. These metals are implicated in atherosclerosis, cancer, and genetic disorders, emphasizing the critical need for monitoring and mitigating their environmental impacts [10].

2. The Dangers of Soil Contamination from Military Operations and Solutions

Military activities have been shown to cause extensive and enduring environmental degradation. Wars fought worldwide during the 20th and 21st centuries have resulted in severe damage to the environment, especially to the soil. The deployment of powerful military machinery and the use of substantial ammunition quantities have led to widespread soil damage across large areas in Ukraine. Russia's armed aggression has directly resulted in uncontrolled alterations to the geochemical composition of soils in war zones [11].

Under natural conditions, trace element and heavy metal concentrations in soils typically increase with depth, sourced primarily from soil-forming rocks. However, during wartime, the influx of heavy metals into the fertile soil layer on agricultural lands can result from ammunition depots and destroyed equipment, and from soil-forming rock being ejected and mixed with soil during explosions. These changes can have long-term detrimental effects on public health and agricultural product quality.

Soil degradation resulting from military actions encompasses not only direct combat but also strategies aimed at undermining the enemy's resource base. Worldwide experience demonstrates this through the destruction of infrastructure, industry, and food supplies, intentional mechanical soil damage, and chemical introduction leading to fires and deforestation. Ukraine currently faces all these challenges due to ongoing conflicts.

The Russian-Ukrainian war, especially since the full-scale invasion on February 24, 2022, has seen the use of an extensive arsenal of weaponry, military equipment, and ammunition. All these forms of military-technogenic stress contribute to severe pollution and soil cover destruction. Ammunition detonations generate shock waves and dispersing explosion products that permeate the environment, causing widespread soil deformation in all directions [12, 13].

Ammunition combustion, explosion, and detonation result in various toxic byproducts that infiltrate the soil alongside water and ammunition fragments. The extent of environmental impact from ammunition use depends on explosive substance transformation speed and projectile explosive substance mass. Military equipment deployment further intensifies territory contamination with oil products, lead, and aromatic hydrocarbons.

Continuous combat activity leads to soil accumulation of lead, cadmium, and petroleum products. These pollutants primarily amass in the soil initially, redistributing within the soil and into other environments, including surface and underground waters and vegetation, eventually entering the soil-plant-human trophic chain. Predicting pollutant migration in such a complex soil system is challenging due to the need to consider numerous variables over time and space, encompassing physical and chemical soil parameters, environmental conditions, and pollutant forms [13].

The mobility of soil pollutants and their subsequent plant uptake depend on soil physical and chemical properties such as granulometric and mineralogical composition, humus content, cation exchange capacity, and redox conditions. Predicting pollutant migra-

Table

Approximate scale for assessing soil pollution hazard based on TPI [9]

Rating of soil pollution	TPI	The impact of soil pollution on health indicators
Acceptable	≤ 16	Lowest level of morbidity in children and minimal functional abnormalities in adults
Moderately dangerous	16–32	General increase in morbidity
Dangerous	32–128	Elevated morbidity, particularly among children and those with chronic diseases
Highly dangerous	> 128	Rising incidence of childhood illnesses and impaired reproductive health in women, such as increased cases of pregnancy-related toxicosis, premature births, stillbirths, and infant hypotrophy

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tion can be achieved by identifying landscape-geochemical barriers, which signify changes in soil characteristics and migration conditions, influencing pollutant accumulation. Therefore, soil restoration planning should involve detailed area studies to assess pollution levels and landscape-geochemical conditions affecting pollutant redistribution [13].

Soil pollution severity significantly worsens with prolonged and intense hostilities, leading to ecological deterioration. Prolonged combat activity with intermittent bombardment exacerbates pollutant dispersion and concentration restoration to background values. Conversely, continuous hostilities create a cumulative effect from ongoing pollutant influx, leading to concentration increases, accumulation, and cross-environmental migration conditions. Extensive combat activities compromise landscape self-recovery capability, necessitating substantial restoration funding.

Russia's armed aggression against Ukraine has triggered uncontrolled geochemical soil composition changes in active combat zones. Heavy metals' content typically increases with soil depth due to natural sources from soil-forming rocks. During wartime, increased heavy metal levels in the fertile soil layer result from ammunition depots, destroyed equipment and soil-forming rock ejection and mixing with soil mass during explosions. These alterations pose long-term threats to population health and agricultural product quality [13, 14].

Certain metals such as cadmium, lead, nickel, mercury, and chromium are classified as dangerous carcinogens by various organizations including the American Conference of Governmental Industrial Hygienists, the IAC Commission (Germany), and the International Agency for Research on Cancer. These metals can cause irreversible changes or damage in genetic material that controls somatic cells, posing significant health risks to humans and animals. As a result, national and international regulatory bodies have established strict guidelines for controlling the levels of these metals in food products. For instance, the Order of the Ministry of Health of Ukraine No. 7 dated January 13, 2006, and international standards like CODEX ALIMENTARIUS outline specific limits and monitoring requirements for these hazardous elements to protect public health.

The experiences of countries where military operations have occurred or are ongoing demonstrate the profound impact of warfare on natural environments, particularly on soils. Studies have highlighted that military actions exert a significant influence on the resilience of soils to combat-induced pollution. However, scientific advancements in monitoring and conducting ecological-geochemical assessments of soil conditions in conflict zones remain fragmented. This underscores the urgent need to address the issue of conducting geochemical analyses and assessing the ecological state of territories affected by military actions. According to the Center for Public Monitoring and Control, every projectile, mine, or aerial bomb that falls on Ukrainian soil not only claims the lives of our defenders and civilians but also harms soil fertility (Figure).

The Ukraine State Environmental Inspectorate estimated that Russian forces contaminated over 280,000 square meters of soil with hazardous substances within the first ten months of full-scale war. Ukrainian Environmental Protection Organization projections suggest nearly a third of Ukrainian areas may be contaminated with ammunition and hazardous substances. In some frontline areas, soil heavy

Figure. Examples of soil pollution after military operations [12]

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metal content is up to 25 times higher than normal levels.

During the G20 summit in Indonesia on November 15, 2022, Ukrainian President Volodymyr Zelensky condemned Russia's war as ecocide, emphasizing global repercussions. He highlighted forest destruction, catastrophic impacts on nature reserves, and contamination of over 200 thousand hectares with ammunition and fragments [12].

The destruction of centuries-old fertile soil layers results from rocket explosions, artillery shells, high-explosive aerial bombs, drones, multiple-launch rocket systems, vacuum bombs, etc. Soil fertility loss stems from altered physical, chemical, and physico-chemical properties. Soil pollution not only diminishes cultivated area fertility but also impacts human health. Harmful soil substances infiltrate groundwater and crops directly.

Post-war soil surveys in Kharkiv region conducted by specialists of the NSC "O. N. Sokolovsky Institute of Soil Science and Agrochemistry" reported nickel, copper, chromium, cadmium, and lead levels exceeding background levels. The impact on chernozems is evident, with systematic 6—8 times mercury, zinc, and cadmium level exceedances [13].

Currently, research is actively investigating patterns of soil contamination by explosive compounds and heavy metals, as well as their distribution among different plant species globally. For instance, biomonitoring studies have shown increased lead accumulation in Spanish pine trees at unregulated firearms ranges, which were characterized by elevated soil levels of lead (Pb) and copper (Cu). Additionally, dandelion leaves growing in war zones exhibit high absorption rates of metals of military and man-made origin, including arsenic (As), barium (Ba), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), vanadium (V), and zinc (Zn) [15].

Separate studies have identified potentially toxic levels of lead (Pb), copper (Cu), and nickel (Ni) accumulating in forage plants on former military training grounds in Switzerland. Furthermore, specific areas in Kosovo heavily bombarded with shells containing depleted uranium still show increased accumulation of uranium in lichens [16, 17].

TNT and its transformation products are recognized as highly toxic to soil fauna, although different species exhibit varying levels of susceptibility to these pollutants. The impact of TNT and other chemical munitions can significantly suppress soil microbial activity [18].

Dangerously high levels of explosive compounds leached from munitions, along with numerous toxic substances resulting from the use of various weapons systems during military exercises of the US Navy, have been identified in the coastal areas of Puerto Rico [19]. Recent studies examining the trace element composition of marine and terrestrial plants in this region have revealed high concentrations of lead, indicating the dispersion of pollution and bioaccumulation of toxic substances within the marine food chain [20]. Monitoring of liver and kidney levels of lead and cadmium in sheep living on farms near military training grounds has shown values exceeding control limits. Conversely, research from Norway suggests a low risk of excessive copper and lead exposure to sheep grazing systematically on former military training grounds [21].

Contamination of the region's land and water resources with mercury, lead, copper, magnesium, lithium, TNT, and depleted uranium has resulted in an extremely high level of morbidity among the population in households residing near the open reef [22]. Specifically, inhabitants of Vieques Island, situated within the military-technogenic influence zone (military training ground), exhibited significant excesses in the content of lead (Pb), aluminium (Al), cadmium (Cd), uranium (U), and arsenic (As) in urine compared to the background values of trace elements characteristic of the archipelago's population. Moreover, arsenic (As), cadmium (Cd), iron (Fe), vanadium (V), and aluminium (Al) levels in blood serum and hair were several times higher in individuals living within areas impacted by military and technogenic influence compared to uncontaminated areas [22].

Numerous studies have highlighted the adverse consequences of military-technogenic influence on the health of children residing in conflict zones. Growth retardation and neurological development in children have been associated with intrauterine exposure to heavy metals, primarily arsenic (As), barium (Ba), and molybdenum (Mo) [23]. The increased number of preterm births and prevalence of birth defects in newborns in the Gaza Strip have been attributed to heightened exposure of the female population to high levels of barium (Ba), arsenic (As), cobalt (Co), cadmium (Cd), chromium (Cr), vanadium (V), and uranium (U) [24, 25]. Additionally, research has demonstrated a link between neurological development disorders in children and the war

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zone environment in Iraq [26].

In Ukraine, the presence of exploded ammunition remnants and newly established Russian military warehouses in occupied areas pose serious environmental risks. Detonations and fires at these sites release toxic heavy metal compounds like lead, mercury, strontium, and magnesium into the air. Since acquiring long-range artillery systems, Ukraine's Armed Forces have destroyed numerous ammunition and fuel storage sites, significantly contaminating soils and water in occupied regions with heavy metals [27, 28].

Agricultural lands in Ukraine are either fortified or contaminated due to conflict-related activities like shelling, fires from ammunition warehouses, and the presence of unexploded ordnance and minefields. Unexploded ammunition sinks into wet soil, corroding over time and releasing toxic substances into the soil, groundwater, and eventually into plants and animals, posing long-term risks of heavy metal poisoning across the affected biocenosis.

Reports from Russian-occupied Donetsk and Luhansk regions highlight severe environmental deterioration due to abandoned mine water pumps, causing excess heavy metals and toxins to seep into groundwater and rivers like the Komyshuvaha, Kryvyi Torets, Siversky Donets, Don, and the Azov Sea. This unchecked pollution poses significant health and environmental risks [29].

For 8 years (2014–2022), Russian occupation authorities intentionally caused ecological disasters in temporarily occupied territories, even amid limited hostilities as per the Minsk agreements. Regions occupied by Russia since February 24, 2022, due to ongoing intense warfare, may already be nearing a similar ecological crisis less than two years into full-scale conflict. Therefore, it's crucial to study experiences from other conflict zones to develop post-war recovery strategies that address the environmental impact of hostilities [30].

Ukraine's post-war recovery presents unique challenges, particularly because even the regions liberated during the Ukrainian Armed Forces' counteroffensives in 2022 are considered among the most heavily mined areas since World War I. Assessing the extent of mine contamination in both temporarily occupied territories and active frontlines is complex. However, due to the intensity of hostilities, southern regions like Mykolaiv, Kherson, and Zaporizhzhia may have significantly higher densities of explosive devices per unit area compared to northern regions like Kyiv, Chernihiv, and Sumy [11].

The challenges of post-war reconstruction in zones of intense combat operations are primarily linked to environmental oversaturation with heavy metal compounds and their sources – various explosive devices and equipment left behind in the combat zone. Damaged and burnt equipment remaining in combat areas, on roads, and in open terrain rusts and breaks down over time due to environmental factors, especially weather conditions, thereby saturating the soil and water with metal corrosion products. Considering that Russian occupying troops utilized nearly all types of conventional weapons in the war against Ukraine post-February 24, 2022, except for nuclear weapons, it's evident that tasks such as demining de-occupied territories and restoring combat zones to a minimally usable state for agriculture will not only require many decades and significant investments but also pose a highly complex challenge for specialists [31, 32].

The experience of other countries in post-war recovery, which economists are currently referencing to develop strategies for Ukraine, encounters significant obstacles that hinder its direct application to Ukrainian circumstances.

The intensity of hostilities in Ukraine's East and South can be likened in scale to the Western Front battles of the First World War, particularly during the battles for Verdun and Ypres, where the latter was entirely destroyed due to extensive bombings. Former combat zones along the front line were heavily littered, prompting post-war reconstruction efforts that involved zoning and economic feasibility analyses. The region was categorized into three zones [32]:

– "Green zone" – areas with minor damage that could be restored relatively quickly for civilian use;
– "Yellow zone" – areas with significant damage requiring substantial investments for long-term restoration to civilian use;
– "Red zone" (a narrow strip along the front line from Lille to Verdun and Nancy) – a zone of active hostilities with extensive damage from unexploded ordnance and chemical contamination by heavy metals and chemical weapons (Pb, Cu, Zn, As, Cr, Ni). Restoration of this area requires substantial investments and is expected to take many decades before civilian use can be resumed.

The problem of post-war reconstruction was also acute for the countries of the Balkan Peninsula in the early 2000s after nearly a decade of hostilities. Similar

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to France, studies of soil samples from former war zones in Croatia revealed significant excess heavy metal content, and subsequent toxicological studies of the population indicated chronic heavy metal poisoning [33, 34].

However, unlike France, which maintained functioning state institutions that facilitated the quick return to civilian use of heavily affected regions, the Balkan countries faced institutional challenges due to the breakup of Yugoslavia and decades of conflicts. This institutional failure hindered their ability to assess the extent of destruction and environmental damage comprehensively, making it difficult to provide adequate forecasts for post-war reconstruction.

The reconstruction efforts were handled locally and chaotically by international organizations, which were unable to coordinate effectively due to the absence of local non-governmental organizations that could provide ecological information and mediate between international organizations and local communities. This chaotic approach resulted in parts of the region remaining heavily polluted with remnants of hostilities and heavy metals even two decades later. In contrast, France successfully returned most of its "Green Zone" and part of its "Yellow Zone" to agricultural use [32].

The chaotic nature and lack of proper coordination in addressing the aftermath of hostilities, including mine clearance and removal of projectile remnants, result in significant delays in these processes. This delay, coupled with metal corrosion and the diffusion of toxic substances into soil and water environments, means that these contaminants will reach animals and humans through food chains, leading to chronic heavy metal poisoning [34, 35].

There is compelling evidence that pollution from heavy metals poses a significant risk to pregnant women. Metals like cadmium, for example, have a specific affinity for placental tissues, leading to various pregnancy complications, including miscarriages. Other heavy metals can disrupt normal fetal development by accumulating in tissues where cells are actively dividing, potentially causing intrauterine malformations. Extensive research conducted on approximately 5,000 newborns in the Gaza Strip from 2011 to 2019 revealed that even with prompt decontamination efforts following hostilities, there remains a risk of chronic poisoning affecting parents and, through maternal exposure, the fetus. These findings highlight the deterioration of reproductive health as a significant consequence of toxicological pollution during conflicts [35, 36].

The main challenge in Ukraine's post-war recovery is the complexity of contamination resulting from a wide range of ammunition used by both sides, covering an area significantly larger than that of West Flanders, which took two decades to restore for agricultural use. Additionally, there is a notable absence of coordination, particularly regarding the demining of de-occupied territories, and a general disorganization in providing information about the consequences of shelling.

For instance, creating a consolidated database for a single day in Kherson requires cross-referencing information from multiple sources, each providing varying details of the same event. Timely access to such consolidated data on shelling consequences could enable the creation of pollution maps, similar to those developed by France after the First World War. Currently, this effort relies on a few enthusiasts collecting data for personal reports and analytical notes, rather than specialized structures tasked with mapping pollution and zoning affected areas, as was done in France.

These historical examples underscore the complexity and time required for post-war recovery in heavily affected areas, suggesting that similar challenges will confront efforts to restore regions affected by recent conflict in Ukraine.

Conclusions

1. Military activities lead to extensive and prolonged environmental degradation, including contamination with heavy metals and other toxic substances, resulting in significant economic, ecological, medical, and social losses.
2. Developing a recovery strategy during hostilities, particularly in areas directly affected by combat, presents a unique challenge. This strategy must be tailored to Ukraine's specific circumstances and cannot fully rely on the experiences of other countries due to ongoing influxes of pollutants from active hostilities.
3. Learning from the experiences of other nations, epidemiological monitoring of heavy metals and their health impacts on Ukraine's population during and after the war should be a key component of a comprehensive research program addressing military-induced environmental and public health effects.

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ЗАБРУДНЕННЯ ҐРУНТІВ ВАЖКИМИ МЕТАЛАМИ ЯК ГІГІЄНІЧНА ПРОБЛЕМА

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Вступ. Ґрунт найчастіше забруднюється сполуками металів та органічними речовинами, оливами, дьогтем, пестицидами, вибуховими й токсичними речовинами, радіоактивними, біологічно активними горючими матеріалами, азбестом та іншими шкідливими продуктами. Джерелом цих сполук є промислові або побутові відходи, захоронені у визначених місцях, або ж у несанкціонованих звалищах. Сьогодні забруднення ґрунтів в Україні є не лише результатом господарської діяльності, а й наслідком воєнних дій, що тривають.

Мета дослідження – аналіз та узагальнення даних світової та вітчизняної літератури з питання забруднення об'єктів довкілля важкими металами внаслідок бойових дій як фактору ризику для здоров'я населення.

Матеріали та методи дослідження. Аналітичний огляд наукових публікацій виконано з використанням інформаційних баз даних PubMed, PubMed, MEDLINE, Free Medical Journals, BioMed Central, Національної бібліотеки України ім. В. І. Вернадського за допомогою інтернет ресурсів.

Результати. Відновлення України після війни передбачає подолання масштабного забруднення важкими металами та вирішення проблем, що пов'язані з видобутком корисних копалин. Територіальний масштаб і складність вимагають довгострокових, ресурсомістких зусиль з відновлення. Порівняльні дослідження наслідників попередніх війн виявляють комплексні проблеми з відновлення. Так, Франція після Першої світової війни класифікувала пошкоджені війною території на зелену, жовту та червону зони. У свою чергу країни Балканського півострова стикаються з проблемами екологічного та інституційного відновлення після конфлікту. Проблеми післявоєнного відновлення включають координацію, консолідацію даних і довгостроковий токсикологічний моніторинг. Вагітні жінки стикаються з підвищеним ризиком впливу важких металів. Дослідники також повідомляють про збільшення захворюваності худоби через забруднення ґрунту та води ртуттю, свинцем, міддю, магнієм, літієм, тротилом і збідненим ураном. Проблеми післявоєнного відновлення України відрізняються від традиційних контекстів через триваючий конфлікт і значне забруднення важкими металами. Стратегічне відновлення включає мінімізацію впливу важких металів на вразливі групи населення. Світове співтовариство має активізувати зусилля для боротьби з забрудненням важкими металами в результаті військових операцій. Зусилля повинні бути спрямовані на відновлення функціональності ґрунту, щоб мінімізувати ризики впливу важких металів.

Висновки. Військова діяльність спричиняє масштабну та тривалу деградацію навколишнього середовища зі забрудненням важкими металами та токсичними речовинами, що призводить до значних економічних, екологічних, медичних і соціальних наслідків. Розробка стратегії відновлення для України має відповідати конкретним обставинам і не може покладатися лише на досвід інших країн через постійне забруднення внаслідок активних бойових дій. Після війни всеосяжна дослідницька програма, яка зосереджена на впливах на навколишнє середовище та здоров'я населення, спричинених воєнними діями, має стати пріоритетом.

Ключові слова: ґрунти, важкі метали, забруднення, ризики для здоров'я

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