UDC 637.12
DOI: 10.15587/1729-4061.2025.343273

# REVEALING THE IMPACT OF MILITARY ACTIVITIES ON THE SAFETY OF AGRICULTURAL PRODUCE

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***This study investigates the process of assessing the safety of agricultural produce in the area in the vicinity of military operations.***

***It is known that military operations lead to contamination of the ecosystem with heavy metals. However, it has not been investigated whether contamination with toxic elements and radionuclides of agricultural products occurred in areas where there are no military operations but there is constant movement of military aircraft.***

***This study was conducted in 2025 in an area located within a 50-kilometer zone of military operations. The content of heavy metals in feeds used for feeding dairy cattle and milk was analyzed as toxins can enter milk through feed.***

***The results showed that the mass fraction of Pb (< 0.86 ± 0.26 ppm) and Zn (13.93 ± 4.32 mg/kg) in grass significantly exceeds the regulatory ones. An increased content of Zn was also found in roughage. Its share in straw was 18.27 ± 5.49 mg/kg, and in hay 8.72 ± 3.08 mg/kg. Cow's milk was also contaminated. An increased level of Pb was found in it in May (0.17 ± 0.08 mg/kg) and July (0.18 ± 0.09 mg/kg). An increase in the level of Cd in milk (0.014 ± 0.01 mg/kg) was established.***

***A particular increase in the share of heavy metals in feed and milk was observed in May and July when the intensity of air threats in Sumy oblast increased. In that case, in April the mass share of Pb in milk was within the permissible norms and did not exceed 0.02 ppm. Radiological studies of milk did not reveal contamination with radionuclides. The specific activity of Cs-137 was within the range of 2.54 ± 2.54 – 4.25 ± 2.69 Bq/kg, and the specific activity of Sr-90 was 0.56 ± 0.56 – 1.13 ± ± 0.7 Bq/kg.***

***Therefore, agricultural produce in the areas near the zone of active hostilities cannot be considered safe***

***Keywords: food security, heavy metals, radionuclides, toxic elements, agricultural produce***

*Received 28.08.2025*
*Received in revised form 29.09.2025*
*Accepted date 07.10.2025*
*Published date 29.12.2025*

***How to Cite:*** *Samilyk, M., Bokovets, S., Kovalenko, O., Ryzhkova, T., Hnoievyi, I., Hrinchenko, D., Petrenko, A., Bakhmat, O., Nedilska, U. (2025). Revealing the impact of military activities on the safety of agricultural produce. Eastern-European Journal of Enterprise Technologies, 6 (11 (138)), 47–53. https://doi.org/10.15587/1729-4061.2025.343273*

## 1. Introduction

The availability of sufficient, accessible, and safe food for people is the main objective of food security, which in turn is an integral part of achieving national security [1]. As a result of military operations, a number of important socio-economic and environmental problems arise that affect life safety, health, food, and energy security.

According to the United Nations, the Russian-Ukrainian war has disrupted food exports, which are critical for low-income countries, affecting an estimated 1.7 billion people [2]. As this has led to acute hunger for 276 million, it can be argued that the food system in the conflict-affected regions is vulnerable.

Current studies on the war in Ukraine have focused mainly on the human and economic impact of the war, with less attention paid to environmental threats. However, it is precisely the disruption of the ecological stability of the territories in the war zone that has dire consequences in the context of food security. This is explained by the fact that there is a threat not only to the quantity of agricultural produce grown but also to its safety.

Despite the fact that military operations in this country have been ongoing for more than 10 years, no studies have been found related to establishing the impact of military aggression on the safety of agricultural produce in the territories of the regions where hostilities are underway. The issue of a comprehensive approach to studying the impact of war on the safety of raw materials for the manufacture of food products remains unresolved.

This problem is especially relevant given the role of Ukraine in the global agricultural resource sectors. This gap in research emphasizes the need for a more thorough study of how war affects the safety of agricultural produce.

## 2. Literature review and problem statement

It has been shown in [3, 4] that the war in Ukraine has a much greater impact on the environment, in particular because of the use of new types of weapons. The results of the reported studies reveal that shell bursts, contamination with fuel and lubricants, as well as explosive residues enter the soil, changing its chemical composition and microbiological activity. However, it is not known whether this applies to areas located near the combat zone. Based on the previous results from [5], the war may have a long-term impact on the physical, chemical, and biological characteristics of the soil. As a result, the use of this land for growing food could potentially lead to health problems. Growing agricultural produce on contaminated lands could cause the accumulation of toxins (pesticides, heavy metals, radionuclides) in food products, which leads to various diseases, including cancer and intestinal infections. This also reduces the nutritional value of products and could lead to the release of hazardous substances into water and air. Despite the fact that the impact of military operations on the environment is proven, there are practically no studies on the patterns of the transfer of pollutants into livestock products through the consumption of contaminated plants by animals.

It has been shown that various types of weapons used in combat zones leave behind harmful heavy metal waste or even nuclear waste. This leads to the destruction of the ecosystem and wildlife, such as insects, which are important for pollination and crop production in these areas [6]. However, no data was found of the impact of such types of pollution on milk.

Based on the analysis of various military conflicts, it was established [7] that usually in the territories where active military operations are conducted, Pb, Cd, As, Hg, Zn, and Cu accumulate. Therefore, it is advisable to analyze the proportion of these heavy metals when studying modern military conflicts.

Typically, studies on the impact of the Russian-Ukrainian war on food security are associated with a quantitative assessment of crop losses caused by the war [8] and soil contamination in areas directly affected by military equipment, shells, or other technical means [9, 10]. Despite the large body of research into the impact of the Russian-Ukrainian war on the environment, no direct threat to the safety of agricultural produce in areas near the combat zone has been established.

Thus, the issue of the impact of military aircraft on the contamination of agricultural produce grown in the territories through which they transit by toxic substances remains unresolved. Research on the content of toxic substances in agricultural produce grown within the 50-kilometer zone of military operations could make it possible to establish the level of its safety.

## 3. The aim and objectives of the study

The purpose of our study is to identify contamination of agricultural produce with toxic elements and radio nuclides caused by military operations. The results will make it possible to establish the level of safety of agricultural produce within the 50-kilometer zone of military operations.

To achieve the goal, the following tasks were set:

– to investigate the content of heavy metals (Pb, Cd, As, Hg, Zn, Cu) in feed for dairy cattle (grass, hay, straw);

– to investigate the content of heavy metals (Pb, Cd, As, Hg, Zn, Cu) in whole cow's milk;

– to investigate the specific activity of radionuclides (Cs-137, Sr-90) in milk.

## 4. The study materials and methods

### 4. 1. The object and hypothesis of the study

The object of our study is the process of assessing the safety of agricultural produce in the area in the vicinity of military operations. The subject of the study is the mass fraction of toxic substances in whole cow's milk and feed for feeding dairy cattle (grass, hay, straw); specific activity of radionuclides in milk.

The hypothesis of the study assumes that because of military operations, there is a deterioration in the environmental condition in the territories located in the border regions not only due to direct impact. The fuel that burns during the flight of missiles, drones, and guided bombs contains hazardous substances that accumulate in the air and settle on the soil cover. The accumulation of toxic substances on the vegetation cover could cause them to enter the body of dairy cattle. As a result, it could cause milk contamination. Therefore, it is advisable to conduct chemical and toxicological tests of plant raw materials (cow feed) grown on it. It is also necessary to monitor the impact of plant-based raw materials on the safety of milk. There is no data on the impact of these emissions on soil vegetation and the quality of livestock products, provided that cows are fed feed collected in these territories. The study will prove or disprove the impact of hostilities on the safety of milk produced in the 50-kilometer zone from the border with the aggressor state.

### 4. 2. Materials

Field research was conducted in April, May, and July 2025 in the village of Tovsta, Sumy oblast (Ukraine), which is located 39 km from the border with Russia (Fig. 1). The distance to the combat zone is 20 km.

Airplanes, helicopters, missiles, drones, guided bombs, etc. are constantly moving over this territory.


Fig. 1. Map of the study area (Sumy region, Sumy oblast, Ukraine), represented as a Google map image

### 4. 3. Feed research

Since the research was carried out on behalf of the National Research Foundation, the types of samples, the time, and place of their selection were established by the technical task for the execution of this work.

Grass samples were taken on pastures where dairy cattle graze, from which milk samples were taken. Grass sample G1 was collected in April, G2 in May, G3 in July. To form the samples, the green part of the plants was cut at three different points of the experimental site. The collected plants were thoroughly mixed and an average sample weighing 1 kg was taken. We determined the content of heavy metals (Pb, Cd, As, Hg, Zn, Cu) in grass samples by absorption spectrometry using an AAS-30 spectrophotometer (Germany).

Hay (H) and straw (S) samples were collected in July 2025 at a private household from which milk samples were taken (M1, M2, M3). The mass fraction of heavy metals in the samples was determined by absorption spectrometry using an AAS-30 spectrophotometer (Germany).

### 4. 4. Milk research

Cow milk samples (M1, M2, M3 in April, May, and July, respectively) were collected at private households from cows grazing in the study areas. Whole milk obtained during lunch milking was analyzed. The content of toxic elements in milk was determined by atomic absorption spectrometry using a PinAAcle900T spectrometer (USA).

### 4. 5. Research on the specific activity of radionuclides in milk

The specific activity of the radionuclide Sr-90 in milk was determined by the beta-spectrometric method using a SEB-01-150 spectrometer (Ukraine).

The specific activity of Cs-137 was determined using a gamma-ray energy spectrometer SEG-001-63 (Ukraine).

### 4. 6. Statistical analysis

The final results are represented as the mean ± standard deviation obtained from three independent extracts conducted within three separate studies. The Student's *t*-test was used to assess the statistical significance of the difference between groups. Differences were considered significant at a probability level of $p \leq 0.05$.

## 5. Results of investigating the level of toxins in agricultural produce

### 5. 1. Results of investigating the content of heavy metals in feeds for dairy cattle

Some heavy metals are toxic, especially in significant concentrations. The results of investigating the content of heavy metals in pasture grass are given in Table 1.

The results showed that all grass samples were contaminated with lead (Pb). Its concentration was particularly high in sample G3 (< 0.86 ± 0.26 ppm), collected in July. Such an excess of the World Health Organization (WHO) recommended norm by 43 times is dangerous. In April, the mass fraction of Pb in grass collected on pasture (G1) exceeded the permissible WHO norm by 4 times only. It is worth noting that the intensity of the air threat in Sumy oblast in May and June significantly increased compared to March and April [11].

In addition, an increase in the mass fraction of zinc (Zn) in grass was observed, especially in sample G3 (13.93 ± ± 4.32 mg/kg), which is 23 times higher than the regulatory values.

The mass fraction of Cd, As, Hg, and Cu was within the limits of the WHO recommended concentrations of heavy metals.

Taking into account the results obtained in July, other types of feed used for feeding cows were analyzed. The results are shown in Fig. 2.

It was found that the mass fraction of Pb in hay and straw is slightly lower than its amount found in green wild forages (0.4 ± 0.15 mg/kg and 0.54 ± 0.18 mg/kg, respectively).

Table 1

Heavy metal content in pasture grass

| Indicator | WHO recommended permissible concentration, ppm | Sample | | | Difference error, % | HIP | |
|---|---|---|---|---|---|---|---|
| | | G1 | G2 | G3 | | 0.05 | 0.01 |
| Mass fraction of lead, mg/kg | < 0.02 | < 0.09 | < 0.25 ± 0.11 | < 0.86 ± 0.26 | 4.173 | 11.602 | 19.198 |
| Mass fraction of cadmium, mg/kg | < 0.3 | < 0.007 | < 0.037 ± 0.02 | < 0.04 ± 0.03 | 4.659 | 12.951 | 21.430 |
| Mass fraction of arsenic, mg/kg | – | < 0.00025 | < 0.0001 | < 0.0001 | 4.708 | 13.088 | 21.657 |
| Mass fraction of mercury, mg/kg | – | < 0.002 | < 0.002 | < 0.002 | 4.705 | 13.081 | 21.644 |
| Mass fraction of copper, mg/kg | < 10.0 | 1.84 ± 0.80 | 1.54 ± 0.68 | 1.67 ± 0.75 | 2.918 | 8.112 | 13.422 |
| Mass fraction of zinc, mg/kg | < 0.6 | 3.75 ± 1.70 | 4.51 ± 1.99 | 13.93 ± 4.32 | 7.026 | 19.533 | 32.322 |

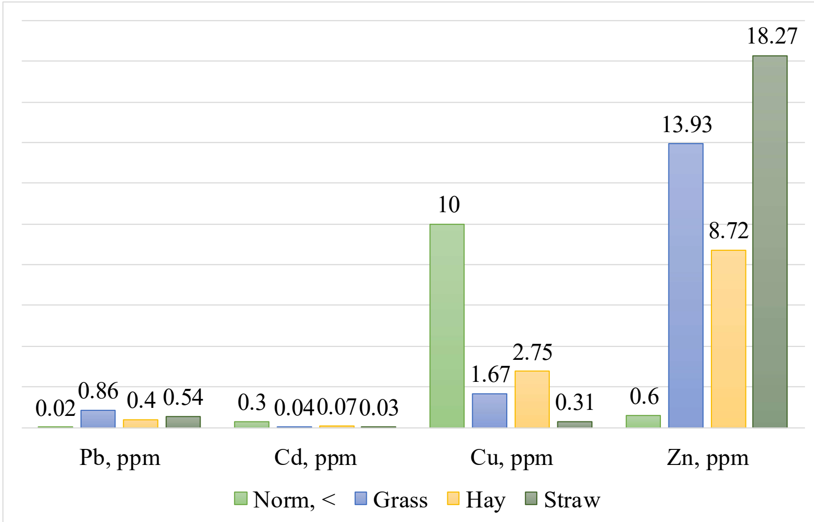


Fig. 2. Heavy metal content in dairy cattle feed in July

The highest content of Zn was found in sample S (18.27 ± 5.49 mg/kg). This value is 30 times higher than the WHO recommended norm and may pose a potential danger to farm animals and humans.

A high content of Cu was found in hay (2.75 ± 1.15 mg/kg), but its mass fraction was within the permissible norm.

### 5. 2. Results of investigating the content of heavy metals in cow's milk

The results of investigating the content of heavy metals in milk are given in Table 2.

It was found that the mass fraction of Pb in milk, as in grass, was 9 times higher than the regulatory values. Importantly, in May (0.17 ± 0.08 mg/kg) and July (0.18 ± 0.09 mg/kg). At the same time, in April the mass fraction of Pb in milk was within the recommended norm.

In addition, an increase and excess of the permissible concentration of Cd was recorded. Its highest content, which was 5 times higher than the norm, was recorded in sample M2 (0.014 ± 0.01 mg/kg). A rather high concentration of zinc was recorded in sample M3 (3.2 ± 1.52 mg/kg).

### 5. 3. Results of investigating the specific activity of radionuclides in milk

In order to establish the safety of milk, the content of radionuclides was analyzed (Fig. 3).

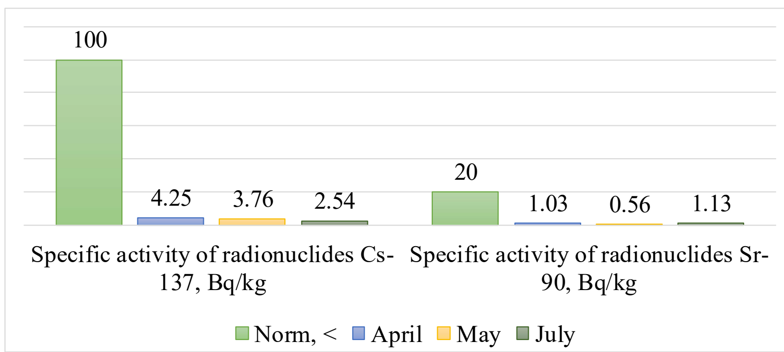


Fig. 3. Specific activity of radionuclides in milk

The results of our study showed that the specific activity of radionuclides in milk did not exceed the maximum permissible limits. The highest level of Cs-137 (4.25 Bq/kg) was recorded in milk in April. The activity of Sr-90 was highest in July (1.13 Bq/kg).

Table 2

Heavy metal content in milk

| Indicator | WHO recommended permissible concentration, ppm | Result | | | Difference error, % | HIP | |
|---|---|---|---|---|---|---|---|
| | | M1 | M2 | M3 | | 0.05 | 0.01 |
| Mass fraction of lead, mg/kg | < 0.02 | < 0.02 | < 0.17 ± 0.08 | < 0.18 ± 0.09 | 4.493 | 12.490 | 20.667 |
| Mass fraction of cadmium, mg/kg | < 0.0026 | < 0.01 | < 0.014 ± 0.01 | < 0.012 ± 0.01 | 4.687 | 13.030 | 21.560 |
| Mass fraction of arsenic, mg/kg | – | < 0.00025 | < 0.0001 | < 0.0001 | 4.708 | 13.088 | 21.657 |
| Mass fraction of mercury, mg/kg | – | < 0.002 | < 0.002 | < 0.002 | 4.705 | 13.081 | 21.644 |
| Mass fraction of copper, mg/kg | < 1.5 | 0.1 ± 0.05 | 0.07 ± 0.04 | < 0.04 | 4.286 | 11.915 | 19.716 |
| Mass fraction of zinc, mg/kg | < 5.0 | 1.57 ± 0.80 | 2.84 ± 1.35 | 3.2 ± 1.52 | 2.509 | 6.974 | 11.539 |

## 6. Results of investigating the safety of agricultural produce within a 50-kilometer zone of military operations: discussion

According to our results (Table 1), the mass fraction of Pb (< 0.86 ± 0.26 mg/kg) in sample G3 was 43 times higher than the WHO standards. There was also an increase in the mass fraction of Zn in grass, especially in sample G3 (13.93 ± 4.32 mg/kg), which is 23 times higher than the regulatory values. Previous studies have shown that increased levels of Zn and Pb in the soil are observed at explosion sites [9], as a result of which heavy metals can accumulate in plants [12]. It is worth noting that previous studies did not reveal an excess of toxic substances in wild forages collected in those areas [13]. The detected changes in the chemical composition of forages in May-July indicate a significant anthropogenic impact associated with hostilities. Such changes not only worsen the condition of the vegetation cover but also directly affect the toxicity of agricultural produce. The results given in Table 1 have confirmed our hypothesis.

After assessing the content of heavy metals in feed, as shown in Fig. 2, it turned out that the mass fraction of Pb in hay and straw was slightly lower than its amount found in green wild forages (0.4 ± 0.15 mg/kg and 0.54 ± 0.18 mg/kg, respectively). High concentrations of Pb in grass are dangerous because it is a toxic substance that can enter the body through inhalation of dust, ingestion, or contact with the skin, causing serious health problems, in particular damage to the nervous system, anemia, kidney, and cardiovascular problems, as well as general weakness, headache, and memory problems, which leads to serious health consequences.

Pb entering the food chain threatens food safety and human and animal health. Pb concentration in soil and pasture grasses used for cattle farming [14] affects milk quality.

The highest Zn content was found in sample S (18.27 ± 5.49 ppm). This value is 30 times higher than the WHO recommended limit and may pose a potential hazard to farm animals and humans. Heavy metals may accumulate more in green grass than in hay due to direct deposition and absorption of atmospheric pollutants on the leaves of living grass. Roughages are less likely to retain surface pollutants. Soil properties and plant uptake efficiency may also vary but the main factor is the living, open surface of green grass, on which heavy metals can directly deposit and be absorbed from the environment. These results are consistent with previous studies [15]. The negative effects of high Zn levels in the body may cause side effects such as nausea, vomiting, loss of appetite, abdominal cramps, and diarrhea [16].

The values of toxic indicators obtained during the analysis of milk, given in Table 2, indicate an increase in the mass fraction of Pb, which was 9 times higher than the WHO recommended regulatory values, especially in May (0.17 ± 0.08 ppm) and July (0.18 ± 0.09 mg/kg). At the same time, in April, the mass fraction of Pb in milk was within the recommended norm [17]. An increase and excess of the permissible concentration of Cd was recorded. Its highest content, which was 5 times higher than the norm, was recorded in sample M2 (0.014 ± 0.01 ppm). Such results indicate that military actions lead to contamination of milk with heavy metals within a 50-kilometer zone while in some studies [18] it was noted that the increase in the proportion of Cd in milk occurs only as a result of the use of veterinary drugs and contamination of feed with natural toxins. It has also been reported that milk is contaminated due to the use of agrochemicals and the misuse of chemicals during processing, manufacturing, packaging, storage, handling, and pasteurization [19]. The accumulation of Cd in milk may pose a health risk, especially at prolonged exposure. Although the levels of cadmium in milk samples may not be immediately dangerous, chronic exposure could lead to various health problems. Cadmium is a known carcinogen and can damage multiple organ systems, including the kidneys and reproductive system.

It was established that the specific activity of radionuclides in milk (Fig. 3) produced in areas where there is no active hostilities does not exceed the maximum permissible limits. Such milk is not contaminated with radionuclides but is not safe due to the high level of some toxic elements (Table 2).

Taking into account all our results, whole milk produced within the 50-kilometer zone of military operations requires careful control over safety indicators before processing and consumption.

The practical significance of our results is that they may prove useful for milk processing enterprises and farmers. In addition, there are possibilities of applying the findings for strategic planning and substantiation of directions during post-war reconstruction of national food security in general and its agricultural sector. A real assessment of the safety of agricultural produce from the territories within a 50-kilometer zone from the border with the aggressor state will make it possible to establish the scale of the impact of military actions and assess the real threat to food security and sustainable development of the region as a whole. For the Mykolaiv territorial community in Sumy oblast, where the test samples were taken, the data obtained could become the basis for devising a post-war recovery strategy and will also make it possible to take immediate measures to increase the safety of agricultural produce.

The limitations of our study include the absence of maximum permissible levels of all heavy metals in roughage (hay, straw), which does not make it possible to fully establish the scale of contamination of agricultural produce in border areas.

The disadvantage of this study is that the milk from only one private household in the settlement was analyzed, although previous studies [17] reported the results of analyzing milk samples taken from three settlements of that territorial community.

Therefore, there is a need for further research aimed at monitoring the level of safety of agricultural produce in a given territory.

## 7. Conclusions

1. Our analysis of the content of heavy metals in grass has revealed that the mass fraction of Pb (< 0.86 ± ± 0.26 mg/kg) and Zn (13.93 ± 4.32 mg/kg) in sample G3 significantly exceeds the maximum permissible standards established by WHO. The mass fraction of Zn in straw (18.27 ± ± 5.49 mg/kg) is 30 times higher than the recommended concentrations of this toxin.

2. The proportion of Pb in whole cow's milk also exceeded the permissible level by 9 times, especially in May (0.17 ± ± 0.08 mg/kg) and July (0.18 ± 0.09 mg/kg). It was found that raw milk in the territory near the combat zone was contaminated with Cd; the highest content (0.014 ± ± 0.01 mg/kg), which exceeded the norm by 5 times, was recorded in May.

3. As a result of radiological studies, it was established that milk produced within the 50-kilometer combat zone was not contaminated with radionuclides (Cs-137, Sr-90).

## Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

## Funding

This study was funded by the National Research Foundation of Ukraine within the framework of research 0125U001049 "Studying the impact of hostilities on the possibility of obtaining safe agricultural produce."

## Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

## Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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