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# Assessment of soil and geological environment contamination caused by hostilities in Mykolaiv region as a result of Russian military aggression against Ukraine

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***SUMMARY***

The article addresses one of the most severe and long-term environmental consequences of armed conflicts, which are the pollution and degradation of land resources. The war in Ukraine has caused significant damage to soil and geological environments, affecting agricultural productivity and ecosystem stability. Soils absorb the direct impact of military actions and hostilities, leading to contamination and long-lasting environmental risks. Explosions, heavy military equipment movement, fortifications, landmines, and chemical spills contribute to soil destruction, compaction, and pollution.

This study focused on assessing soil and groundwater contamination in the Mykolaiv region, one of the most affected areas as a result of russian aggression. Soil samples were collected from combat zones and adjacent territories to evaluate chemical degradation. The results indicate excessive levels of phosphorus, likely due to military activities, along with high concentrations of arsenic. In some cases, arsenic contamination was also detected in underground aquifers, posing risks to water quality and human health. The findings highlight the urgent need for continuous monitoring, environmental restoration, and strategies to mitigate the long-term impacts of war-related pollution.

## Introduction

Among the most dangerous and long-term environmental consequences of armed conflicts and wars are pollution and degradation of the physical condition of land resources (Certini et al., 2013; Broomandi et al., 2020; Altahaan & D. Dobslaw, 2024). Russian aggression in Ukraine also damages one of the main wealth of the state - soil resources. Soil takes the brunt of military operations, suffers from major pollution and, as an inert component of the ecosystem, can bear the consequences of war for a long time. Explosions of missiles, air bombs, artillery shells, movement of heavy military equipment, construction of fortifications, mining, spills of fuel and lubricants and other hazardous substances cause the formation of craters, destruction of the soil cover and underlying rocks, pollution and compaction of soils, rocks of the aeration zone, groundwater.

About 15 million hectares of land have been affected by the war, and most of them are extremely important for agricultural practices. The total area of such land in temporarily occupied, deoccupied and frontline territories reaches 20% of the territory of Ukraine, which indicates a significant destruction of the country's agricultural potential (Baliuk at al., 2024). This area suffers from the mechanical, physical, chemical, physicochemical and biological degradation of soil. At the same time the main attention in studies of the impact of war is paid to the chemical degradation of soils caused by contamination with toxic elements, in particular heavy metals, petroleum products, radionuclides, dioxins, etc. Determining the level of soil contamination is the basis of the national methodology for calculating the damage caused by military actions (Romanenko, Krysinska, & Tymchenko, 2024). In many cases, soil contamination is a component and indicator of larger-scale contamination of the geological environment (Shekhunova et al., 2022), which includes contamination of rocks in the aeration zone and groundwater (Havryliuk et al., 2024).

Mykolaiv region is among the regions of Ukraine that suffer the most from russian aggression along with Kherson, Zaporizhia, Donetsk, Luhansk, and Kharkiv regions. According to (Soil contamination…, 2024), as a result of hostilities and shelling, the soils of Mykolaiv region have been significantly contaminated with hazardous substances, the losses from which are estimated at about 1 billion euros. It has been established that in some areas of Mykolaiv region, the concentration of lead exceeds its MPC by 5 times, and the content of zinc, copper, fluorine, and petroleum products by a quarter (Bulba et al., 2024). At the same time, a significant territory of the regions affected by military actions requires more thorough research and monitoring of land resources and the geological environment. Therefore, the purpose of this research was to further assess the chemical contamination of soils and the geological environment of Mykolaiv region as a result of Russian armed aggression.

## Method

To study the impact of military operations on the soils of the Mykolaiv region, the territories suffered from active hostilities were selected (Fig. 1). The selection of study areas also took into account security conditions. Soil samples were taken in the Mykolaiv territorial community (Mykolaiv city), Pervomaiska community (Partyzanske village, Blagodatne village), Halytsynivska community (Limany village, Lupareve village, Prybuzke village). Groundwater samples were taken from wells that provide centralized water supply to the villages of the Halytsynivska community.

The first stage of soil sampling took place on December 2, 2023. In the front-line communities of Pervomaiska (Fig. 1b) and Halytsynivska, soil samples were taken in a crater (sample 1, Fig. 1a) and on agricultural land (samples 2, 3, 4, Fig. 1a). During the sampling period, there was no plant vegetation. The second stage of soil sampling took place on February 18, 2024. In the Halytsynivska community, soil samples were taken in areas affected by shelling, in particular on uncultivated agricultural land (samples 5, 7 Fig. 1a), and cultivated, previously mined, agricultural land (sample 6, Fig. 1a). Samples 8, 9 were taken in areas of active hostilities in the Pervomaiska community. During the sampling period, plant vegetation was absent.

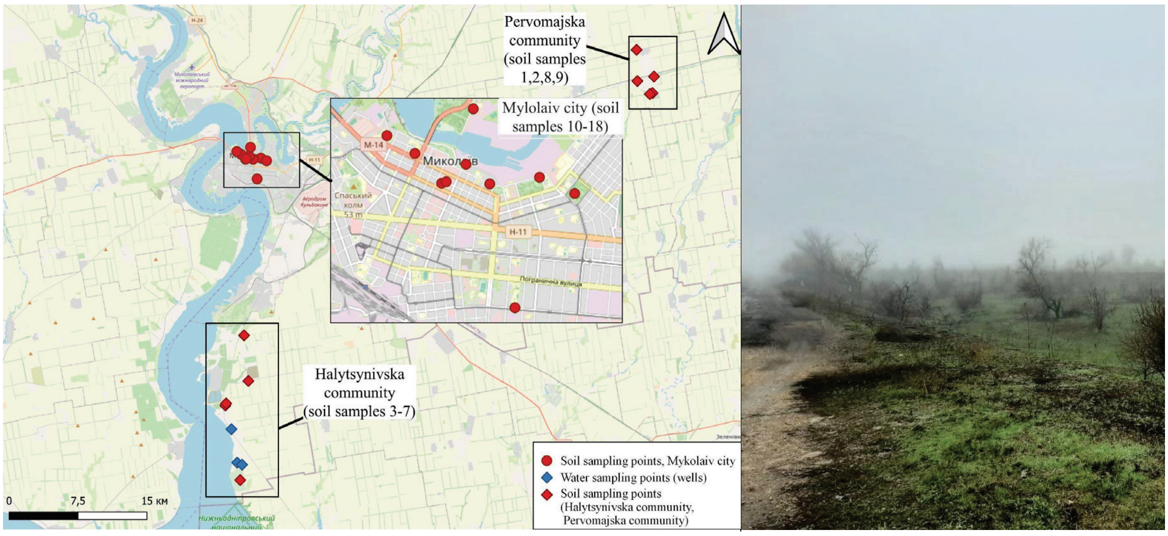


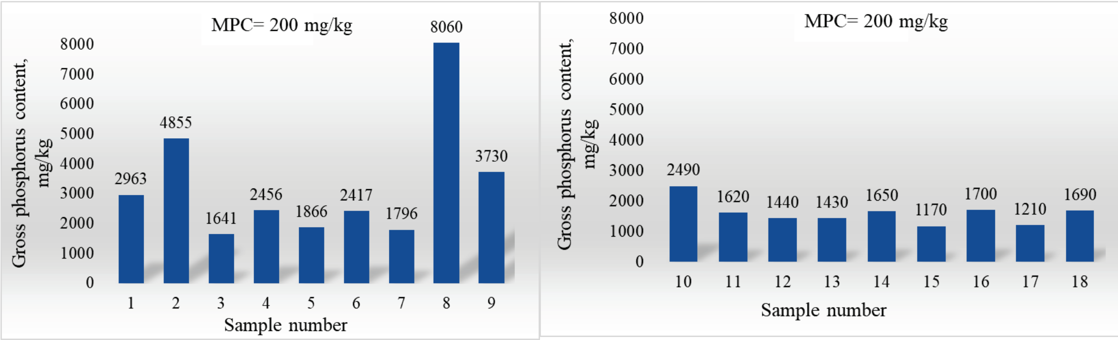

***Figure 1*** *Map-scheme of soil and groundwater sampling points (a), soil sampling area in the Pervomaiska community, 02.12.2023 (b).*

The third stage of soil sampling was carried out from August 7 to 11, 2024 in the city of Mykolaiv. 8 soil samples were taken from the recorded places of arrivals, ruptures and falls of fragments of various shells: C-300, X-22, Caliber missiles, FAB-500 aircraft bombs, etc. (samples 10–17). Control sample of soil #18 was taken in a place where there were no explosions, it served to determine background concentrations of pollutants. In the area where soil samples were taken, prevailing lowland grassy cereal vegetation, mature tree plantations were recorded.

Soil samples were taken using a metal bayonet shovel in the depth range of 0–30 cm and packed in plastic (opaque) hermetic containers. The sampling area was divided into elementary plots (at least 5), where spot samples were taken for further mixing into a combined sample. The mass of each soil sample was at least 500 g. Instrumental analysis of the samples was carried out in the laboratories accredited for compliance with the requirements of ISO/IEC 17025.

**Results**

The most significant excesses of the maximum permissible concentrations (MPC) were recorded for the gross phosphorus content. Phosphorus pollution is widespread (Fig. 2), which is likely related to the agricultural use of phosphorus fertilizers. Long-term studies of the weighted average content of mobile phosphorus compounds in the soils of the Mykolaiv region in the pre-war period (MDA, 2021) recorded an increased level of its concentration (127-146 mg/kg). At the same time, the peak gross phosphorus content was recorded at the site of the use of phosphorus weapons (sample 8, Pervomayska community). However, mobile phosphorus concentration (110 mg/kg) in this sample did not exceed the multi-year background. An abnormal concentration of gross phosphorus was also recorded in the zone of intensive hostilities and mined agricultural lands (sample 2, Pervomayska community). This may indicate that a significant amount of phosphorus entered the soil due to military operations. After a certain period of time, such bound phosphorus or part of it can turn into a mobile form available to plants. Within the city of Mykolaiv, the phosphorus content is lower, but also exceeds the maximum permissible values.




a b

***Figure 2.*** *Gross phosphorus content in soils: a – samples from Halytsynivska and Pervomaiska communities (territories of hostilities and those bordering them), b – samples from Mykolaiv city, sites of shelling during 2022-2024. MPC - maximum permissible concentration.*

Determination of phosphorus content can be useful in terms of determining the rate of transition of bound arsenic into a mobile form available to plants and migration into groundwater. Significant increases in arsenic values were recorded in all soil samples both within the frontline communities and within the city of Mykolaiv (Fig. 3). Particularly high content was recorded in the rocket crater (sample 1). High phosphorus levels are one of the factors that increase arsenic mobility through competitive adsorption (Matzen et al., 2022).

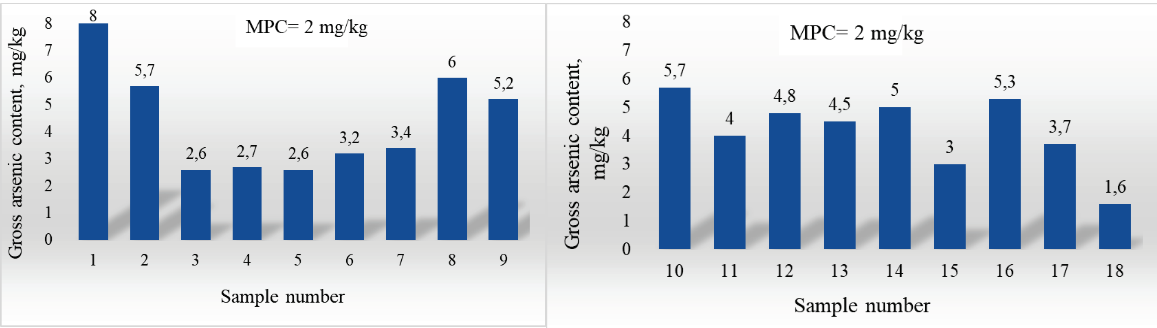



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***Figure 3.*** *Gross arsenic content in soils: a – samples from Halytsynivska and Pervomaiska communities (territories of hostilities and those bordering them), b – samples from Mykolaiv city, sites of shelling.*

Arsenic was also recorded in the groundwater of the Upper Sarmatian aquifer, which is used for water supply of the Halitsynivska community (the villages of Lymany and Lupareve). At a MAC of 0.01 mg/dm$^3$, its content reached 0.22 mg/dm$^3$. The nature of groundwater contamination requires further study. The depth of the wells is 50–60 m, which indicates a certain protection of groundwater from technogenic pollution from the surface in this area. At the same time, the presence of technogenic pollutants in the aquifer, which is the main source of groundwater in the Mykolaiv region (Shestopalov et al., 2024), indicates the likelihood of significant negative consequences from its contamination.

**Conclusions**

The results obtained indicate chemical contamination of the soils of the studied areas of the Mykolaiv region. These areas were affected by hostilities. Hot spots of phosphorus contamination are confined to the places of use of phosphorus weapons, intensive hostilities and mined areas. High phosphorus levels are one of the factors that increase the mobility of arsenic through competitive adsorption on mineral soil particles. Significant increases in arsenic concentrations were recorded in all soil samples taken both within the frontline communities and within the city of Mykolaiv, and a particularly high content was recorded in the rocket crater. The detected arsenic contamination of groundwater is of a technogenic nature, could potentially be associated with hostilities and may cause significant negative consequences for people.

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