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This article explores the environmental impact of armed conflict, highlighting its severe and long-term effects on ecosystems, wildlife and resources. Chemical pollution, physical exposure, and munitions threaten human life, wildlife, and soil, increasing long-term risks. The factors of the negative impact of military operations on ecosystems, soil and water resources are considered. Remote sensing is presented as one of the tools for tracking damage, including fires, artillery shelling, erosion, and landscape changes.

Key Words : ***Landscape, soil contamination by shells, remnants of weapons, chemical contamination, erosion processes, remote sensing, migration of hazardous substances, contamination of large areas, consequences of accidents, nature reserve fund.***

Russia's full-scale invasion of Ukraine, which began in February 2022, has had serious consequences that go beyond the economic, cultural, and social spheres. One of the lesser-known aspects of these consequences is the environmental dis-

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aster, which includes environmental degradation and serious damage to Ukraine's natural resources. From this perspective, we can speak of the systematic and deliberate destruction of natural ecosystems and resources, which can sometimes be even more serious than general military operations.

Data provided by the Ministry of Environmental Protection and Natural Resources of Ukraine indicate that as of March 20, 2022, military operations covered the territory of the nature reserve fund, which amounts to 12.4 thousand square kilometers [1]. This is equivalent to a third of the total area of the nature reserve fund of Ukraine and poses a threat to many unique ecosystems and species of international importance.

For example, military operations, in addition to threatening human life and health, are also accompanied by the movement of heavy equipment, construction of fortifications, and damage to soil cover. This leads to degradation of vegetation, increased wind and water erosion, and threats to large natural reserves, including the Emerald Network (a network of protected areas created to preserve species and habitats in need of protection at the European level. The Emerald Network is being formed in non-EU countries and is similar to the Natura 2000 network that operates in EU countries. [3]), which is the last refuge for many species of plants and animals. In addition, migration routes of numerous species of birds and mammals cross the war zone, which can lead to difficult challenges for their survival and reproduction.

This environmental crisis could also spread beyond borders of Ukraine, leading to contamination of aquatic and marine ecosystems, groundwater, and possible radiation, chemical, and toxic pollution. The damage to Ukraine's nature and environment has already exceeded $38 billion [2], and this figure may be growing, as experts have not yet been able to gain access to the occupied territories and the frontline zone. Environmental inspectors are actively working on docu-

menting and assessing the damage in order to ensure that the aggressor country receives reparations.

In this context, our article consider the impact of military operations as a factor in the destruction of soil and the agricultural environment in Ukraine. We explore the natural and ecological aspects of this extremely important issue and emphasize the need for global attention to the environmental consequences of military conflicts, as well as the need for restoration and protection of the natural environment during and after war.

The use of various weapons during the hostilities on the territory of Ukraine leads to serious changes in the terrain and landscape of these lands. The level of damage directly depends on the characteristics of the weapon used, such as the force of the explosion, the number of weapons used, and the density of fire damage. The processes of soil damage can be divided into two main groups. The first group is primary damage, which includes direct mechanical deformation of the soil cover and contamination by shell fragments. The second group is secondary damage, which occurs as a result of the failure to implement strategic post-war recovery measures. These include flooding, salinization, erosion processes, pyrogenic degradation, and dehumidification［4］. Military actions have a complex impact on the soil cover, including mechanical, physical and chemical effects. These impacts lead to the destruction of the structure and functions of the soil ecosystem, which leads to the deterioration of soil properties. The results of the impact may vary depending on the type and kind of hostilities, terrain, soils and protective structures in a given area.

Vegetation disturbance, soil destruction, loss of natural moisture, and desertification are common consequences of military-technogenic impacts that lead to a significant reduction in biological populations, biodiversity, and changes in the structure and function of landscapes.

If available into account the factors, one can predict and assess the impact in a specific area by considering factors, parameters, and the intensity of the negative effects.

Physical deformation of the soil includes the formation of craters caused by the impact and rupture of shells. During this process, the upper and middle layers of the soil (sometimes even the lower layers, depending on the type of projectile) rise, which leads to a complete transformation of the structure and mixing of the soil in the area of impact. A significant negative physical factor is also the movement of troops and the construction of fortifications. Most of these impacts result in soil compaction with damage to the humus horizon, which leads to a violation of the soil's water balance and the development of erosion processes, both water and wind. The movement of military equipment also can to create ruts and multi-track roads, filled with water, which contributes to waterlogging.

The destruction of soil structure occurs due to the movement of one layer of soil particles relative to another under the influence of military-technogenic load. This movement can cause liquefaction of water-saturated dispersed soils and their transition to a liquid state [4]. This process causes the destruction of the soil structure and loss of the density of connection between the particles. This results in the complete destruction of the soil structure, which negatively affects its physical properties and ability to support vegetation.

The unexploded ordnance hidden in the war-torn land poses a particular threat not only to people, animals and agricultural machinery, but also to the environment as a whole. These unexploded ordnances have the potential to contaminate the soil not only with metals but also with various chemical compounds, which can significantly increase the risk of fires and cause even greater negative environmental impact. It is important to remember that these shells remain potentially dangerous for many years after the end of hostilities.

According to the UN, Ukraine is currently one of the most mined countries in the world. More than 80 thousand square kilometers of Ukraine's territory need to be clear of mines and explosive remnants［5］. The process of demining towns and villages is out more quickly, but forests remain uncleaned for decades to come. This situation poses serious threats to security and the environment, and complicates the further use of these territories.

The physical negative impact of the hostilities is accompanied by the release of a number of chemical pollutants. These chemical changes in the soil composition directly affect the vegetation cover, making natural selection for plants more difficult. This is especially true for trees and other large plants, which may not be able to germinate on contaminated soil. As a result, steppe zones with only grass and shrubs can form.

Soil contamination can also lead to groundwater contamination, which can harm flora and fauna, resulting in the death of ecosystems due to toxicity.

Sulfur is a component of many types of munitions. Sulfur released as a gas and mix with precipitation during military operations and explosions. This process produces sulfuric acid. This acid has a negative impact on the soil environment and plants, in particular by changing the acidity（pH）of the soil. Sulfur emissions are a prerequisite for the formation of acid rain, which can affect plants, groundwater and the environment outside of military operations. Such acid rain can change soil quality and cause burns to plants. This will have negative consequences for biological populations, vegetation cover and overall ecosystem health.

In addition, the chemical compounds released into the soil during the explosion of shells include other toxic substances and heavy metals. These substances can contaminate the soil and leach into groundwater, which can affect human health and the natural ecosystem. All of these factors together create a serious chemical footprint that can leave long-term effects and lead to a ban on the use

of contaminated land in the future.

Chemical contamination from vehicle fuels, lubricants, electroplating waste, explosive residues, decontamination agents, heavy metals, and in addition, during military operations, units use different types of ammunition with different compositions of powder and explosives. The explosions produce toxic gases, including carbon monoxide, carbon dioxide, water vapor, nitrous oxide, nitrogen dioxide, formaldehyde, cyanide, and others. In places where active hostilities took place, there is a systematic 6-8-fold excess of mercury, zinc and cadmium, and 30-fold excess of heavy metals [6]. Heavy metals, such as lead, copper and other components, are contained in artillery shells and can to transform into toxic compounds that enter the soil and water, thereby threatening human health and the environment.

Ammunition fragments dispersed during an explosion also contain heavy metals and other hazardous substances that can accumulate in the soil and create negative impacts over many years.

The use of chemical weapons is particularly dangerous in the long term. Today, in particular, there are documented cases of the use of white phosphorus in the areas where hostilities took place. When white phosphorus is burn, is produced white smoke in the air, consisting mainly of phosphorus trioxide (P4O6) and pentoxide (P4O10).

The formed phosphorus oxides are extremely hygroscopic and quickly absorb moisture, forming a number of phosphorus-containing acids, such as orthophosphoric (H3PO4), pyrophosphoric (H4P2O7) orthophosphoric acid (H3PO3), hypophosphoric acid (H3PO2), polyphosphoric acids of the general formula Hn+2PnO3n+1 (where n=2−8) and a number of other linear and cyclic polyphosphates P6-P16. The composition of chemical compounds formed due to of phosphorus combustion changes over time. In conditions of insufficient oxygen, the

combustion of white phosphorus can produce phosphine（PH3）[7]. The phosphorus that remains after an explosion, despite the fact that the active burning of phosphorus does not last long, can leave a trace in the soil, especially if the projectile hit below the topsoil. This can significantly affect the pH（acidity）of the soil. In addition, some of the chemicals may enter the groundwater and be transported to other locations, further contaminating the environment.

When chemicals migrate through groundwater, they can get to areas where erosion processes are already underway. When chemical compounds enter the soil, they begin to act on vegetation, which holds the soil with its root system. As a result, plants that slowed down the erosion process begin to die, which in turn accelerates soil erosion due to the effect of these chemicals on the vegetation cover, as a prerequisite for increasing the intensity of degradation processes.

In addition to the direct military and technological impact on ecosystems and landscape structure, there is a risk of larger-scale disasters due to the possibility of attacks on chemical plants, nuclear and infrastructure facilities.

During the 512 days of the war, experts in environmental protection and natural resources of Ukraine recorded about 2,500 cases of violations of environmental standards by the aggressor's troops. For example, because of the explosion of the Kakhovka Reservoir, Ukraine lost 18 billion cubic meters of water, which falls squarely within the definition of ecocide. [8]

The drying up of the Kakhovka HPP causes serious changes in the hydrological regime of neighboring areas and has irreparable consequences. To monitor these consequences, scientists are successfully using remote sensing data.

The drying up of the reservoir will significantly affect the water system of nearby communities. The reduction in the reservoir area will result in limited access to water for drinking, irrigation, and industrial use. Farmers who relied on the reservoir for irrigation needs will face problems in growing food crops, rais-

ing livestock, and fishing. As a result, the loss of the hydroelectric power plant as a source of energy will affect industrial processes and production that depended on this electricity in cities such as Nikopol, Marhanets and Kryvyi Rih, which require significant amounts of water, may be severely limited due to water shortages. The reservoir's drying up can also lead to environmental consequences, affecting the local ecosystem and biodiversity. Declining water levels disrupt the living space for aquatic plants and animals, including national parks such as Kamianska Sich and Velykyi Luh, which can lead to ecosystem imbalances and threats to species [9]. Overall, the reservoir's drying up will create a critical situation in the water management and economic sector of the adjacent territories, and it is important that the government and communities act proactively by implementing contingency measures to mitigate the negative impact on water availability and the well-being of the local population.

To identify and assess damage, especially in hazardous areas, it is often advisable to use remote sensing data. They will allow to accurately identify the size of the areas affected by military operations and have undergone significant changes. Aerospace imagery can reveal the locations of fires and artillery shelling that have caused serious damage to the landscape and changes in the terrain.

Spectral analysis using satellite data can help define the level of soil erosion and the extent of landscape damage. EO Browser, a platform for visualizing and downloading available medium- and low-resolution imagery, including the Scene classification map product, can help to track devastated transformations of the areas by military operations and define the size of the desertification zone.

The use of the NDMI spectral index will allow us to assess the decrease in moisture, which is an important indicator of vegetation damage. Changes in humus and soil pH will indicate the migration of chemicals in groundwater, which can have a serious impact on the environment.

The NDVI vegetation index make to possible to identify the condition of vegetation and identify damaged forests. Retrospective imagery will help accurately assess the damage and extent of the damaged forest.

The use of remote sensing technologies will help to create a detailed map of the areas that need to restore after the end of hostilities. They can also be useful for registering the work done after military restoration and calculating the total damage for future reparations.

All of the above data and analyses indicate that military conflicts and hostilities have a serious and far-reaching negative impact on the environment and ecology. Disruption of the normal functioning of ecosystems, environmental pollution and damage to natural resources create serious problems for people, animals and nature.

Remote sensing tools are proving to be extremely useful for tracking and assessing environmental damage during military conflicts. Aerospace imagery, spectral analysis and other remote sensing techniques allow us to identify fire locations, landscape damage, changes in vegetation and many other aspects. The involvement of remote sensing in the processes of restoration and damage assessment allows not only to accurately defining the state of natural resources, but also contributes to the development of strategies and measures for the restoration and preservation of nature.

To summarize, given the complexity and duration of the impact of the consequences of military operations on the territory of Ukraine due to Russia's armed aggression, it is difficult to assess its environmental impact due to the difficulty of access to the sites of hostilities. However, with the help of remote sensing technologies, we can develop and respond appropriately measures in advance and calculate the damage to the territory of Ukraine and assess it. Such measures will not allow Russia to hide its actions. In the context of a full-scale armed conflict,

it is important to remember to develop effective strategies for restoring war-damaged land, eliminating the consequences and, in the end, restoring the ecological balance of ecosystems affected by the conflict.

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