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LAND DEGRADATION IN UKRAINE AS A RESULT OF MILITARY OPERATIONS

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ABSTRACT

Motives: Ukraine, like many other countries worldwide, faces a serious problem of land degradation as a result of military operations. Military conflicts, such as those that have occurred in eastern Ukraine since 2014 and throughout the entire territory since 2022, have a significant impact on natural ecosystems and land resources, increasing the risk of environmental problems and health threats to the population. It is worth noting that military operations directly damage agricultural land through explosions, gunfire, and heavy machinery, resulting in destruction and pollution. In particular, this affects soil fertility and structure, which are essential for healthy agriculture and farming.
In addition, military operations often involve the use of chemicals that can have long-term negative effects on soil quality and water resources. Toxic substances, radiation, and other military remnants can remain active for decades, contaminating natural resources and harming the health of local populations. Restoring land after military action requires significant resources and time. Restoring ecological balance and rehabilitating soil and water ecosystems are complex tasks that require coordinated efforts at the national and international levels.
The article highlights the problem of Ukrainian land degradation in active conflict zones, manifested in intensified processes such as wind and water erosion. A proposal for possible land restoration measures was made.
Aim: The aim of the study was to identify and analyze the impact of armed conflict on the quality and condition of land resources in the country, and to find possible ways to restore land degraded as a result of military operations.
Results: When studying the environmental consequences of military conflicts, the authors of the article focused on analyzing soil contamination, destruction of infrastructure, and degradation of natural landscapes, including forests and agricultural lands. It was found that military actions pose significant environmental risks due to the use of weapons of mass destruction, artillery explosions, and chemical contamination, which can have long-term effects on human health and natural ecosystems. The concentration of titanium in soil samples collected at the rupture site was 150 times higher than the background level. The maximum permissible levels of vanadium, lead, and cadmium in soil were

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exceeded. At the moment of the explosion, many compounds such as CO, CO_2, H_2O, NO, N_2O, NO_2, CH_2O, HCN, N_2, and a large number of toxic substances are formed. The primary mechanical impact on the soil is compaction, which damages the humus layer and has direct negative consequences, including disruption of the soil's water balance and triggering of wind and water erosion.
Mine clearance activities also have a negative impact on the soil – typically, the humus horizon is destroyed, the physicochemical properties of soil are lost, and changes in its granulometric and aggregate state occur. This, in turn, affects the fertility and water retention capacity of soil.
Military actions affect the lithogenic foundation of soil due to the construction of technical structures, the laying of transportation routes, the creation of craters, and the intensive destruction of the surface layer of soil. Forest fires caused by artillery explosions and military equipment destroy hundreds of thousands of hectares of vegetation, valuable plant species, and have a negative impact on wildlife. Surface and groundwater are contaminated as a result of combat activities. An example of an anthropotechnogenic disaster is the blowing up of the Kakhovka reservoir dam by Russian forces. Military actions lead to the deterioration of economic and social living conditions in the country: during the years of the war, 84,979 tons of oil products were burned, and 294,242 tons of harmful substances were released into the atmosphere.
Land affected by the adverse effects of military operations can be restored and cleaned through reclamation. The choice of reclamation technology depends on the nature and degree of contamination, the intended use or purpose of the land to be restored, and the availability of effective and economically efficient technologies. It should be noted that the selection of land restoration methods involves a cumulative assessment of the level of damage, which includes determining the category of suitability for land use.
The research highlights the need to protect the environment from the effects of war and to implement strategies for the restoration of natural resources after the end of military conflicts. It is emphasized that the demining of agricultural lands is an extremely serious problem that Ukraine cannot solve on its own.

Keywords: land degradation, military operations, demining of agricultural lands, sustainable development, restoration of ecosystems, ecological consequences of armed conflicts, reclamation

INTRODUCTION

Land resources are essential factors in the life of humanity. They shape the political, economic, and social components of societies living within specific territories, significantly influencing the development of national economies by ensuring the stable and rational utilization of fertile lands for the agro-industrial complex.

Ukraine stands as one of the world's richest countries in terms of the quality characteristics of its land resources.

In the context of rapid societal development, the anthropogenic impact on the planet's natural resources continues to increase, leading to irreversible degradation processes. Each year, the relentless depletion of natural resources weakens the stability of natural ecosystems, reducing their capacity for self-regeneration and self-regulation.

However, throughout human history, land has been a constant object of warfare.

War poses a threat not only to life and health today but also in the long term. One of the menacing factors is complex environmental pollution. Among all ecosystems negatively affected by war, soil suffers the most.

War has caused unprecedented damage to both populations and ecosystems, resulting in emergency environmental crises such as fires, destruction, and the hazardous contamination of air, soil, and water with toxic chemicals and petroleum products. The adverse impact of human activities on nature and the environment for military purposes is referred to as biocide (environmental warfare).

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Today, weapons of mass destruction-including nuclear, chemical, biological, and bacteriological weapons-possess the greatest destructive potential. All components of the natural environment, primarily humans, are defenseless against these types of weapons.

Resources are a major source of conflict between nations, as a country's survival often depends on natural resources. The concept of waging war by destroying the environment in which the enemy resides is not new.

The Vietnam War had a significant impact on the environment due to the chemicals used to defoliate military vegetation.

Not only vegetation was affected, but also wildlife: "In a study by Vietnamese ecologists in the mid-1980s, only 24 species of birds and 5 species of mammals were recorded in the cleared forests and the reconstructed areas. In contrast, there are 145–170 species of birds and 30–55 species of mammals throughout the undisturbed forest" (Sploditel et al., 2023, p. 9). Currently, the long-term effects of these herbicides appear uncertain due to changes in species distribution patterns resulting from habitat degradation and the loss of wetlands that serve as continental runoff absorbers. Never in the history of military conflicts have industrial and chemical facilities suffered such large-scale bombings as observed in Yugoslavia. Clouds of benzopyrene and soot were observed in Bulgaria, Romania, much of Serbia, western Ukraine, Belarus, Poland, and parts of the Baltic states. Additionally, in northern Greece and Macedonia, air pollution associated with dioxin exceeded permissible levels by 15–20 times.

For Macedonia, the main identified threat is soil disturbance in refugee camps. Due to the Kosovo crisis, the Republic of Macedonia is hosting more than 250,000 refugees from Kosovo on its territory, even though it can accommodate only 20,000. During the Kosovo crisis, Macedonia exceeded its capacity by almost 12.5 times. Refugees in the country make up more than 12.5 percent of the country's population, or about 2 million people. Camps were built in Macedonia to receive refugees, including Blace, Stenkovec, Radusha, Bojane, Neprošteno, Senokos, and Chegrane, covering a total area of 98.1 hectares. The existence of refugee camps indirectly affects the environment in the country.

Since Albania has limited agricultural land, one of the main negative effects of the conflict in Kosovo is the construction of refugee camps on arable land. Consequently, hundreds of hectares of land were removed from economic activity. The influx of refugees has caused significant damage to protected areas along the Adriatic coast in western Albania. Due to the lack of modern measurement tools, cross-border pollution control is not effectively carried out. Refugee camps damage fertile soil, national parks, and nature reserves.

Military activity results in large-scale and long-term environmental degradation. The experiences of countries where military operations have occurred or are ongoing testify to their significant influence on all components of the natural environment, particularly on soils. Studies have shown that military actions have a profound impact on soil resilience to combat-induced pollution. However, scientific developments in the field of monitoring and ecological-geochemical assessment of soil conditions in the context of military conflicts remain fragmented. This highlights the need to address the problem of geochemical analysis and the assessment of the ecological state of territories that have been destroyed or polluted due to military actions.

LITERATURE REVIEW

The definition of war by scientists is often interpreted as a planned human action aimed at causing significant harm to other members of society with the goal of territorial conquest. Historically, military strikes have primarily targeted enemy troops, with limited consideration for the environmental impact and its consequences.

Undoubtedly, the issue of soil pollution and degradation warrants a rigorous theoretical, methodological, and scientific-practical exploration.

In recent years, the number of scientific publications by domestic researchers on topics related

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to land use economics, land management, land monitoring, and land governance in domestic journals has increased. Several relevant monographs, reference works, and educational materials have been published. Furthermore, economists, ecologists, and land managers have contributed articles to international scientometric databases such as Scopus and WoS. Balyuk S.A. is reasons causing degradation processes, and put forward measures of their preventing aimed at reproduction of fertility of soils for reaching neutral level of degradation (Balyuk et al., 2022). Velichko V.A. claims that it is necessary to create a system of permanent monitoring of land using remote sensing data of the Earth, as well as research study soil cover, introduction of national geospatial data infrastructure (Velichko et al., 2020). Dobryak D.S. and Kanash O.P. developed a classification of arable land according to its suitability for growing agricultural crops, taking into account the specific features of the natural and ecological conditions of the environment (Dobryak et al., 2009). Dorosh J.M. and Martyn A.G., studied the basis of socio-economic and ecological problems of land use, in the volume including responding to global challenges (Dorosh et al., 2021). Medvedev V.V. outlined the methodological principles and procedures for conducting soil monitoring based on European experience (Medvedev, 2012). Novakovsky L.Ya. considered the problems of forming a rational system of land use, creating ecologically balanced landscapes (Novakovsky et al., 2019). Tarariko O.H. identified critical zones of erosion degradation of arable lands, requiring preservation and their inclusion tothe natural fi elds, which had a positive impact on the optimization of agrolandscape diversity (Tarariko et al., 2019). Tretyak A.M. developed proposals for amendments to the current legislation for the organizational basis of land management of territorial communities, which will improve the financial condition (Tretyak et al., 2021). Libanova E.M. and Khvesyk M.A. formulated strategic directions for the rationalization of all spheres resource use based on the evaluation of improvement of the land resource management system (Libanova & Khvesyk, 2014). Sploditel et al. (2023) study the impact of military actions on soils by assessing their ecological and geochemical condition in active combat zones. The authors have identified criteria for soil contamination based on the degree of damage and propose main measures for the post-war restoration of Ukrainian soils, taking into account regional landscape-geochemical characteristics and types of land use. In the collective monograph edited by Gorb et al. (2023) he research results on the protection and restoration of ecological balance and the provision for ecosystem self-renewal are presented. The authors explore the possibility of restoring degraded and polluted lands using innovative technologies. The work examines the international practice (of the Persian Gulf, the former Yugoslavia, Kosovo, the Gaza Strip, Lebanon, Sudan) of assessing the negative impact of military actions on land resources. Horishnyi et. al. (2023) use public data on environmental risks and damages to highlight the impact of military actions on Ukraine's environment. They apply analytical calculations based on generally accepted research methods in the field of ecology. They indicate that the armed conflict in Ukraine has disrupted monitoring, protection, and management systems of the environment, undermining the environmental rights of Ukrainian citizens.

Scientific research on the consequences of armed conflicts for the environment, soil, and natural resources is a highly important topic for international scientists. They investigate various aspects of this issue. The article by Broomandi P. et al. (2020) is aimed at reviewing the physical and chemical disturbances in soils following military activities, approaches to characterizing contaminated military sites, and progress in human health risk assessment to evaluate potential adverse impacts. The authors aimed to provide a critical discussion of the environmental impact of military activities (training and war) on soils, approaches to characterizing contaminated sites, and the progress and challenges in characterizing human health risks. Gambuzza V. et al. (2023) noted that from 2000 to 2010, there were approximately 30 state armed conflicts worldwide, and in the last decade, this number has doubled. They point out

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that one of the consequences of building military bases is habitat destruction, soil erosion, and chemical contamination. The maintenance of equipment and infrastructure generates hazardous waste, such as corrosive substances, paints, fuels, and especially heavy metals. They indicate that armed conflicts impact both micro and macro levels, involving direct effects on people and the environment and indirect effects on planetary health through increased industrial emissions.

Considering the current problems in the context of the armed conflict in Ukraine, the issues of land protection and monitoring are extremely relevant and require further research.

MATERIALS AND METHODS

In the latter part of the 20th century, a large-scale survey of the soil cover of agricultural land was conducted in Ukraine, covering an area of over 42 million hectares. This survey, which remains unparalleled worldwide, resulted in the creation of soil plans and a series of soil maps ranging from district to national scales, including 1:200,000, 1:750,000, and 1:1,500,000 scales. These efforts also led to the development of recommendations aimed at enhancing land use efficiency and increasing soil fertility. Subsequently, selective additional soil surveys were carried out, a nomenclature list of agrogroups was compiled, and a geobotanical survey of natural fodder lands was undertaken.

These materials served as the foundation for land evaluation, the maintenance of records regarding the quantitative and qualitative composition of land parcels, and the organization of land management planning. Notable outputs include the General scheme of anti-erosion measures, similar schemes for various regions, schemes of anti-erosion measures for rafter-beam systems, basins of individual rivers, and the comprehensive utilization of Lower Dnipro sands. Additionally, working projects for complexes of anti-erosion hydrotechnical structures were developed. To implement these schemes, working and pilot projects were initiated, resulting in the creation of 450,000 hectares of forest strips, the filling and layout of 10,000 hectares of ravines, and the terracing of 15,000 hectares of slopes (Novakovsky, 2020).

To address these challenges, on January 19, 2022, the Cabinet of Ministers of Ukraine formulated the Concept of a target program under the framework of the Law of Ukraine "On the Nationwide Program for the Use and Protection of Land" (On the approval of the Concept of the National target program of land use and protection, 2022).

In the Concept of the National Targeted Program for the Use and Protection of Land for 2022–2032, the Program's objectives are clearly defined, the underlying causes of the identified problems are analyzed, and the proposed solutions are justified using a programmatic approach. The purpose of the Program is determined, and various options for resolving these issues are considered, along with the methods, means, and timelines for addressing them. The Program includes measures such as the development of appropriate land management documentation, the creation of projects, and the monitoring of the implementation of these specified measures. The intent is for land management to once again become a socio-economic and ecological instrument for the implementation of land-related policies, guided by the principle of special protection of land as a unique national asset.

The primary predictive indicator for solving this problem is presented in the Concept, aiming to reduce the territory's plowing level to 44 percent by removing land unsuitable for agriculture. According to expert estimates, this unsuitable land covers an area exceeding 6.5 million hectares. Soil surveys and material corrections indicated that approximately 5.1 million hectares of arable land could be considered for conservation, comprising 54.3% washed away and degraded land, 11.5% overmoistened and waterlogged areas, and 9% saline land (Novakovska, 2017). This area is 1.4 million hectares smaller than the initially proposed figure for land unsuitable for agriculture by experts. However, due to the ongoing state of war that Ukraine has endured for nearly two years, it is likely that the 6.5 million-hectare figure will need to be revised upwards following a comprehensive inventory of the territory and remote land sensing.

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After the initial large-scale study, additional selective soil investigations were conducted. These focused on compiling a nomenclature list of agro-groups and conducting a geobotanical survey of natural forage lands. These additional studies helped refine and update existing data, ensuring their accuracy and relevance for current land management and planning.

It should be noted that during military operations, the occupying forces recklessly destroy not only critical infrastructure and military headquarters but also vital supply routes, civilian structures, agricultural lands, farms, and areas within nature reserves and ecological parks. Therefore, the aim of the presented study is to analyze the level of soil degradation in Ukraine due to the war, followed by determining the strategy for post-war soil restoration based on the assessment of their ecological and geochemical state in areas of active combat, taking into account regional landscape-geochemical conditions and types of land use. This was implemented using the method of remote sensing: utilizing satellite data to monitor changes in the Earth's surface and detect degradation zones allowed for obtaining up-to-date information on the state of land resources, which is critically important for planning the restoration and conservation of ecosystems. The spatial data analysis method allowed for the comparison of various data sets to identify patterns and trends in land degradation.

An integral part of the study is the examination of reports from governmental and non-governmental organizations on the impact of conflicts on land resources, as well as the analysis of existing literature and research concerning land degradation due to military actions, and international experience of countries that have experienced military actions on their territory. The main focus is on practices and national policies regarding the restoration of lands that have been contaminated or directly physically damaged.

RESULTS

Before providing a comprehensive description of the state of soil degradation in Ukraine resulting from the war, let's examine the pre-war indicators of land resource use. This will enable us to conduct a comparative assessment and gain insights into the level of contemporary soil transformation and pollution during the active phase of the conflict.

As of the end of 2021, Ukraine accounted for nearly 10% of the world's wheat exports, 16% of corn exports, and 55% of sunflower oil trade. Over 400 million people worldwide depended on Ukrainian grain supplies (Kulinich & Novakovska, 2022).

Ukraine possesses a land fund comprising almost two-thirds of chernozems and meadow-chernozem soils, positioning it as one of the world leaders in terms of soil resource quality. Chernozem soils represent a significant portion of Ukraine's national wealth, characterized by their deep humus layer, agronomically valuable structure, and abundant nutrient content, all of which contribute to their high potential fertility.

The protection and responsible use of land are considered among the most crucial societal tasks. Overcoming hunger and achieving food security rank second among the 17 Sustainable Development Goals defined by the UN (with land use accounting for 98% of food production).

Based on the analysis, the negative ecological consequences of military actions can be classified as follows:

1. Soil and water pollution.
2. Changes in the biogeochemical balance of the territory.
3. Destruction of water, electricity and gas facilities.
4. Destruction of forests and agricultural lands.
5. Destruction of nature and animals in protected areas.
6. Danger to human health.

Soil pollution

During the war, 3.5 million hectares of spring crops were not sown (according to the press service of the State Ecological Inspection of Ukraine).

The figures are calculated according to the methods that determine the amount of damage caused to land, water resources and atmospheric air.

The total amount of damage caused by soil pollution is more than 688 billion hryvnias.

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The total amount of damages due to atmospheric air pollution is 998 billion hryvnias. And for pollution, clogging of water resources, the damage is estimated at more than 56 million hryvnias.

At the same time, the territorial and interregional territorial bodies of the State Inspectorate from February 24 to January 24 of the full-scale invasion recorded and calculated the quantitative indicator of the damage caused by the occupiers:

- 280,904 m^2 – soils contaminated with hazardous substances;
- 12,277,512 m^2 of land littered with remains of destroyed objects and ammunition;
- 686,816 tons of petroleum products were burned during the shelling, polluting the air with dangerous substances;
- 33,132 hectares of forests and other plantations were burned by rockets and shells, some of them may be restored within ten years, and this is according to the most optimistic calculations, the rest are lost forever;
- 1,063,947 m^2 – objects, including critical infrastructure, were destroyed, their remains caused damage to the environment;
- 1597 tons – the mass of pollutants that entered water bodies;
- 2,903,513 kg – the mass of foreign objects, materials, waste and/or other substances that got into water bodies;
- 410,150,000,000 m^3 – the volume of water collected/used by arbitrary means.

Changes in the biogeochemical balance of the territory

In particular, there is pollution of the atmosphere, soil and water bodies, flooding of territories, disturbance of the habitats of the animal world, destruction of objects of the nature reserve fund, occurrence of forest fires (especially in the exclusion zone, Chernobyl nuclear power plant), etc. As of May 24, 2022, the Ministry of Natural Resources confirmed 254 ecocides and counted 1.5 thousand cases of environmental damage in Ukraine.

During military operations, environmental preservation often takes a backseat, the principle applies as quickly as possible, as effectively as possible, as cheaply as possible. And it leads to fatal consequences for all mankind. The impact of the conflicts themselves on the environment is very different. Some international armed conflicts can be brief but very destructive. There are wars that last for decades, but they are fought with low intensity.

High-intensity conflicts require and consume enormous amounts of fuel, leading to massive CO_2 emissions and contributing to climate change. Large-scale movement of vehicles, intensive use of explosive objects lead to extensive physical damage to sensitive landscapes and geodiversity.

The use of a large amount of herbicides and the use of chemical weapons caused the phenomenon of the destruction of vegetation and the forest as a whole. The vegetation that suffered from these impacts often took decades to recover, and in some cases, recovery was impossible. The reduction of fish stocks and erosion of the coastline of water bodies was caused by the death of the forest massif. The death of some and the prosperity of other species of flora and fauna has become the object of disruption of ecosystem relations. And this process requires a significant period of time for recovery. In some areas, regeneration may not occur at all, which creates terrible conditions for the existence of people and all living things in the environment.

During shelling and bursting of high-explosive charges, pollution of highly toxic substances occurs, which negatively affects not only human health, but also representatives of the plant and animal world. Unpredictable anthropogenic and natural conditions arise on uncultivated fields, which lead to massive overgrowth of territories with weeds. The use of explosive weapons in urban areas creates a huge amount of debris that causes air and soil pollution.

The classification of environmentally dangerous projectiles also includes those that tend to explode in the air. As a result of the use of such weapons, a cloud of aerosol fuel is formed, which explodes after moving in the air space and creates a devastating shock

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wave, which causes terrible destruction, the effect of which is estimated more than the destruction of high-explosive shells.

The use of aviation and artillery in military operations will lead to disruption of the lithogenic basis of landscapes. Because of their action, there is a change in soil properties, their weakening and the appearance of large sinkholes due to the rupture of shells and bombs. When an explosion occurs, there is contamination with chemical substances, contamination with poisonous and powder gases and combustion products, which are negative effects on the environment due to the use of these weapons. Unfortunately, there is such a tendency, all military actions have a devastating effect on natural objects, which is done deliberately with the aim of destabilizing natural ecosystems (Fig. 1).

Periodic shell explosions actually fill the ground with metal, making it almost unusable. In particular, the concentration of titanium in the soil samples at the place of rupture of the shell was 150 times higher than the background value. Exceeding the permissible lvels of vanadium, lead and cadmium content was detected. At the moment of explosion, various compounds including CO, CO_2, H_2O, NO, N_2O, NO_2, CH_2O, HCN, N_2 are generated, along with a multitude of toxic substances. These substances oxidize soil, wood, building structures, and can also have a negative effect on living organisms. Considering this, such high concentrations of various metals make the soil unsuitable for further use. Environmental consequences of military operations also include damage to human health through exposure to hazardous substances, such as inhalation of gases from burning oil fields or uranium dust, which can trigger asthma and possibly lung cancer.

Poisonous substances differ from other combat equipment due to their impressive properties:
- the ability to penetrate from the air and attack personnel in different buildings, tanks and other military equipment;
- the ability to maintain its impressive effects for a long time in the air, on the ground and in various objects;
- are transmitted by airborne droplets and spread over large areas, affecting all persons in the field of their activity without means of protection;
- vapors of poisonous substances can spread over long distances downwind from areas where chemical weapons are directly used.

Given that many chemical substances do not degrade for hundreds of years (and some radioactive substances require hundreds of thousands of years), questions arise about humanity's overall impact on the planet and the potential for significant alterations to the human gene pool.

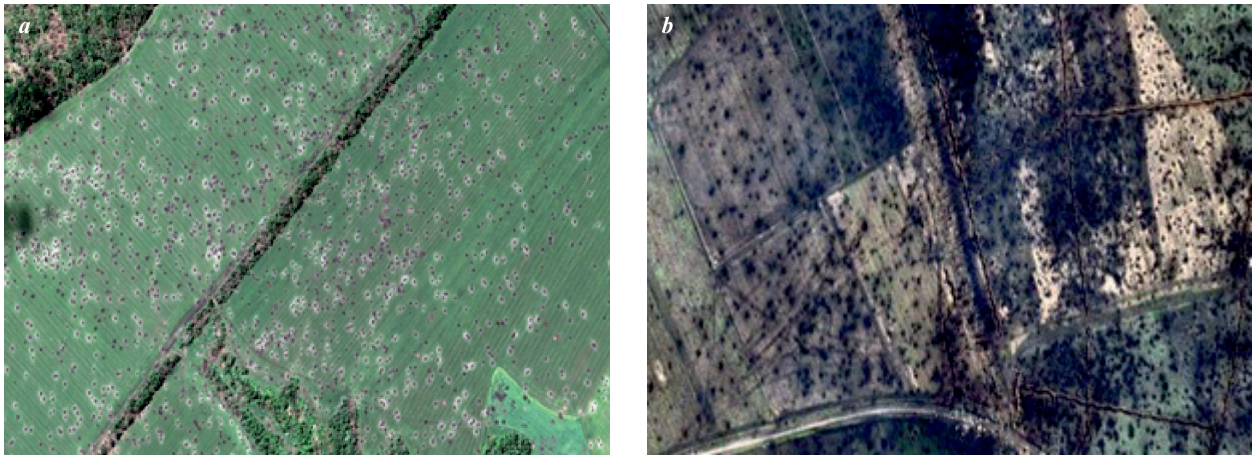

Fig. 1. The density of explosive shells falling on the territory of agricultural lands: a) a section of the Donetsk region (12 hectares of land); b) a plot near the city of Bakhmut, Luhansk region (12 hectares of land)
Source: The war in Ukraine… (n.d.).

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Destruction of forests and agricultural lands

The use of new ammunition and new tactics for the destruction of all living things cause not only the destruction of the animal world, vegetation and soil cover, but also become factors in the emergence of steppe and forest fires due to explosions and the formation of projectile fragments. Scorched earth tactics have been around since ancient times. Flooding can be employed as a scorched earth policy, rendering the land unusable through the application of water.

If as a result of forest fires there is a loss of such basic functions of ecosystems as ecological, sanitary and hygienic, soil protection and water regulation, then steppe fires are characterized by the concept of temporary soil sterilization, during dry burning, which results in the death of the biological component of soils, insects and microorganisms in these areas.

In contrast to the aerosol transport of toxins, there is also the so-called reverse transport. In case of large and permanent fires, the flow of hot air enters the stratosphere. A vapor-gas mixture caught between two layers of cold air can move for such a long time that it is almost impossible to predict in advance where on Earth it will fall to the ground.

Mechanical, chemical and physical impact on the soil

Damage to the soil as a result of military operations can be mechanical, physical and chemical. Each of these influences is critical in its own way and causes destruction of the earth's structure and functions. Let's study each in more detail.

Mechanical influence

Deforms the ground cover, which leads to a violation of the soil structure during the movement of military equipment, the movement of troops, the construction of protective structures, places of bombing (disruption of the ground due to the formation of craters from bombing), demining of territories. The consequence of this impact is compaction, waterlogging, and soiling of the territory with products of combat activity.

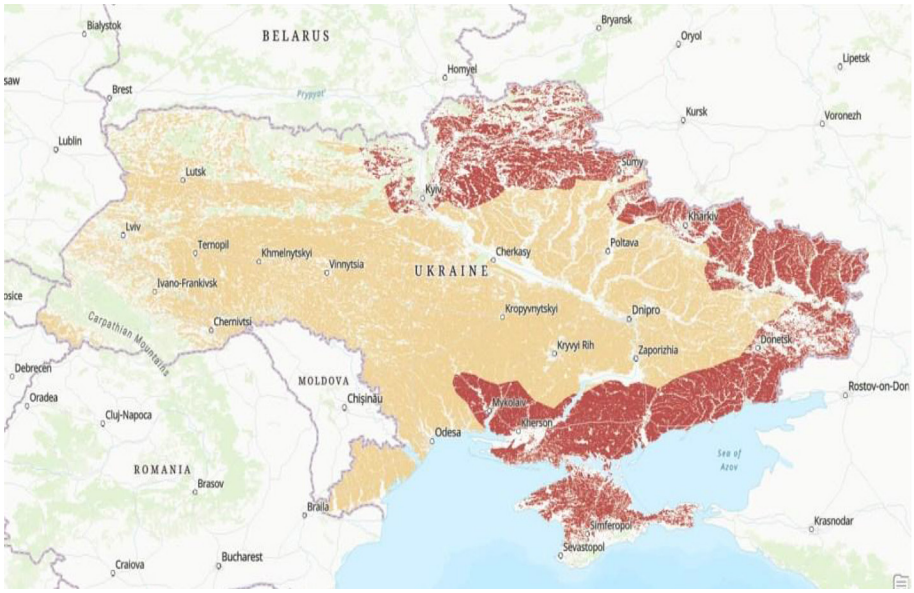

Fig. 2. Contaminated territories of Ukraine as a result of the war (a darker color indicates agricultural landscapes of Ukraine that are within the zone of risky agriculture)
Source: Almost a third of Ukrainian fields… (n.d.).

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The main mechanical impact on the soil is compaction with damage to the humus layer, which has direct negative consequences, in particular, disturbance of the water balance of the soil, and causes the development of wind and water erosion. The destruction of the soil structure occurs as a result of the displacement of the particles of one layer relative to another under the influence of military-technogenic load (Fig. 2).

Separately, it is worth noting that demining territories also has a negative impact – the humus horizon is usually destroyed, the physical and chemical properties of the soil are lost, and changes in the granulometric and aggregate state occur. For its part, this affects the fertility and water-holding capacity of the soil.

Physical impact

Presupposes a change in the physical parameters of the soil as a result of the use of weapons and military equipment. This refers to vibrational, radioactive and thermal effects.

The combination of various influencing factors leads to the emergence of a cumulative negative effect. The consequences are the loss of the soil's buffering capacity for recovery, the loss of humus and a decrease in natural fertility.

It should be added that each of the above-mentioned impacts leads to the destruction of vegetation, disturbance of soil cover, lack of natural moisture and desertification. As a result, the level of biota is also sharply reduced.

Movement of toxic substances and their migration into plant products

A very negative point is that pollutants can move. This happens in two ways: horizontal – occurs immediately after the bombing, primarily due to air transport; vertical – it is associated with such factors as diffusion of ions, transfer with the flow of moisture or plant root systems, activity of soil mesofauna, economic activity of man.

Most often, the migration of pollutants occurs through groundwater, which has the ability to retain heavy metals through selective absorption (adsorption). Many factors influence the proportion of heavy metals that migrate. In particular, the composition of the soil, organic substances in it, humidity, microbiological activity, etc., are important. The presence of plants also affects the mobility of explosives and heavy metals.

Pollution initiates with the absorption of particles through the liquid solution present in the porous soil matrix. This soil solution, containing explosive substance compounds, infiltrates plant roots. These compounds move within the plant roots, eventually becoming sequestered within the plant.

Destruction of nature and animals in protected areas

Military operations affect the lithogenic base of the soil, which is located at a depth of several meters, as a result of the construction of technical structures, the laying of movement routes, the appearance of sinkholes and intensively destroy the surface layer of the soil. In the territories where military operations are taking place, devastating damage is caused to the vegetation, the integrity of the ground cover is destroyed and violated due to the movement of powerful military equipment, tanks and armored personnel carriers, and missile systems. As a result, such processes as wind and water erosion are activated on these plots of land (Fig. 3).

Plant life and forest resources are affected by:

- forest fires caused by explosions of artillery shells and military equipment, destroyed hundreds of thousands of hectares of vegetation, destroyed valuable plant species;
- vegetation affected by the movement of armored vehicles;
- burning of wood to meet the vital needs of people in cities where communications are disrupted, as well as the use of wood for military purposes outside of cities, including for fortification, which leads to unauthorized and unregulated logging;
- vegetation suffers from the harmful effects of acid rain, which occurs as a result of numerous explo-

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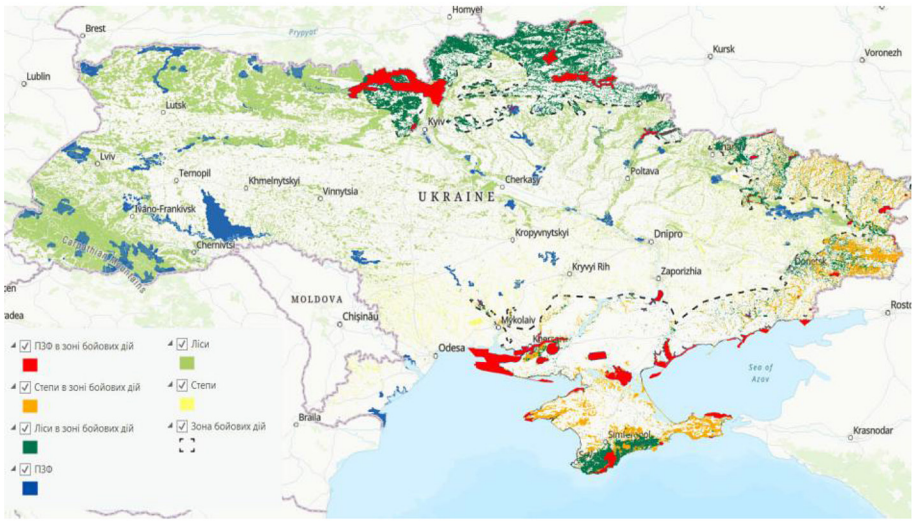

Fig. 3. Visualization of the affected natural territories as a result of the military invasion according to the data of the NGO „Ukrainian Nature Conservation Group"
Source: Almost a third of Ukrainian fields… (n.d.).

sions and large-scale fires, which leads to an increase levels of sulfur dioxide (SO_2) and various nitrogen oxides (NOx) in the atmosphere.

Impact on the animal world:

- due to excessive pollution of water bodies, hundreds of thousands of fish may die, and some populations may disappear completely;
- the action of acoustic systems, powerful explosions, vibration disrupt peacefull existence of animals, leading them astray;
- explosive shells and forest fires led to the death of wild animals, including species listed in the Red Book.

There is a complex impact on ecosystems:

- nature conservation areas serve as centers of biological and landscape diversity, requiring a special regime of activity and scientifically based monitoring measures even in peaceful conditions. However, during military operations, this special system of measures is not implemented within the nature reserve fund;
- hostilities around nuclear power facilities and in the Chernobyl exclusion zone have a complex environmental impact and significant risks. The radioactive background increases as a result of the destruction of the surface protective layer of the soil in dangerous radioactively contaminated territories, which negatively affects the entire natural complex.

Large-scale forest fires negatively affect all components of nature, destroy vegetation, kill animals, cause atmospheric air pollution, as well as due to precipitation, surface water and soil cover.

Like wildlife, ecosystems are polluted by the noise of military aircraft.

Destruction of water, electricity and gas facilities

Resources are a major source of conflict between nations. The country's survival depends on natural resources. Sources of armed conflict include territory, strategic raw materials, energy, water and food. The concept of waging war by destroying the environment in which the enemy lives is not new.

The loss of energy supply can have negative consequences that harm the environment. Stopped work at treatment plants or pumping stations, toxic fuel from domestic generators getting into the soil, can lead to difficult to restore or non-renewable processes in ecosystems.

As a result of hostilities, surface and underground waters are polluted, in particular:

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– discharge of pollutants as a result of damage to processing facilities, industrial facilities and equipment, violation of the integrity of chemical warehouses, etc.;
– spills of oil products, fuel and lubricants, including damaged military equipment on river crossings, ships in the Black and Azov seas;
– explosions of shells, rockets and mines in the waters of reservoirs due to mining of reservoirs and their shores;
– as a result of massive burials, unauthorized landfills, household waste in cities with damaged public infrastructure, damage to equipment in areas of active hostilities near water bodies;
– pollution from the failure of pumping stations that supply water from unmined coal mines.

As a result of the effects of explosive actions from bombs, the groundwater level is disturbed, which leads to filling with rain and melt water and creates favorable conditions for the reproduction of insects.

Artificially created shallow water, pollution of reservoirs, destruction of entire ecosystems of reservoirs can also be observed due to the destruction of dams.

The example of an anthropo-technogenic disaster is the undermining of the dam of the Kakhovsky Reservoir by Russian troops in order to solve their strategic plans. A powerful wave of water swept through the Kherson region with great force and speed, destroying everything in its path, washing away fertile layers of soil, destroying the homes of peaceful people, and after the water receded, turning recently used agricultural land into a desert with unpredictable consequences for the future.

Danger to human health

Military actions lead to the deterioration of economic and social living conditions in the country. Because of hostilities, many harmful and dangerous substances are formed, which are difficult to dispose of and store, and most often no one deals with their disposal and preservation, so they are simply thrown away.

According to the information resource "EkoZagroza" of the Ministry of Ecology and Nature Management, during the war, 84,979 tons of petroleum products were burned, and 294,242 tons of harmful substances were released into the atmosphere. Constant shelling of oil refineries and chemical plants of various specializations (e.g., "Sumikhimprom" in Sumy Region, "Shebelinkagavydobuvanny" in Kharkiv Region, Avdiiv Coke Chemical Plant (AKHZ) of Metinvest Group, and Knauf Plant in Donetsk Region) leads to the emission of toxic gases, carbon monoxide and dioxide, sulfur, dust, soot, lead and its compounds, copper, nickel, which have various toxic and carcinogenic properties (physical and chemical).

As a result of constant shelling, fires broke out at an agricultural enterprise in the Sinelnyk district of the Dnipropetrovsk region, a warehouse for mineral fertilizers (nitrates and nitroammonium) in the Mykolaiv district, and a warehouse for tires and herbicides, an ammonium nitrate warehouse in the Kramatorsk district of Donetsk region, an ammonium nitrate warehouse in the Kharkiv region, a plant of mineral fertilizers in the Odesa region, a warehouse with polyurethane foam, and the territory of the Institute of fiberglass in the city of Irpin, Kyiv region. This is an incomplete list of man-made disasters that directly affect both biota and human health (Fig. 4).

In just one day (April 9, 2022), the cities of Mariupol, Avdiivka, Mar'inka, Vuhledar, Slovyansk, Pokrovsk, Toretsk, Solodke, Novomykhailivka, Troits'ke, Stepove, and Katerynivka were shelled with phosphorus ammunition prohibited by the International Convention. This led to mass fires, chemical pollution of the soil, atmosphere, underground water horizons, and had a devastating impact on human life (phosphorus contact with human skin leads to chemical burns and rapid poisoning of the body). A distinctive feature of this disaster is the fact that the burning of phosphorus does not stop until the process of its complete combustion occurs. Phosphorus combustion products and their solutions form salts in the soil, and white smoke enters the respiratory tract of people.

If it is taken into account, that many chemicals do not degrade for hundreds of years, and the decay period of radioactive elements is even longer,

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Fig. 4. Impact of military actions on the environment of Donetsk region
Source: Environmental damage… (n.d.).

it becomes clear that the military industry is placing a slow-acting mine under the gene pool of humanity.

Landmining also has a major impact on the environment and security. Because of this influence, not only land plots, representatives of the animal and plant world, but also people suffer more and more often. We are already aware of the consequences of mining rural and commercial lands, which lead to the destruction of agricultural, automobile, and cargo equipment and the tragic loss of innocent lives.

To restore and clean these land plots, a process known as reclamation is used. Reclamation is not just a way to clean the land but also a strategic approach to restoring natural ecosystems and preserving the environment; it is the process of transforming contaminated land into a usable area.

The choice of reclamation technology depends on the nature and degree of contamination, the intended use of the restored area, and the availability of effective and economically efficient technologies (Is it possible to cure the soil from war – answers to the most common questions, 2023). However, before selecting a technology, it is necessary to conduct an analysis of the consequences of the combat actions (Fig. 5).

The analysis of the consequences of military actions (Fig. 5) is critically important for the informed selection of reclamation technologies necessary for the restoration of territories. Firstly, it helps assess the extent of damage and determine the level of pollution, which affects the choice of remediation methods. Mechanical impacts in the context of military-technogenic load are manifested through soil cover

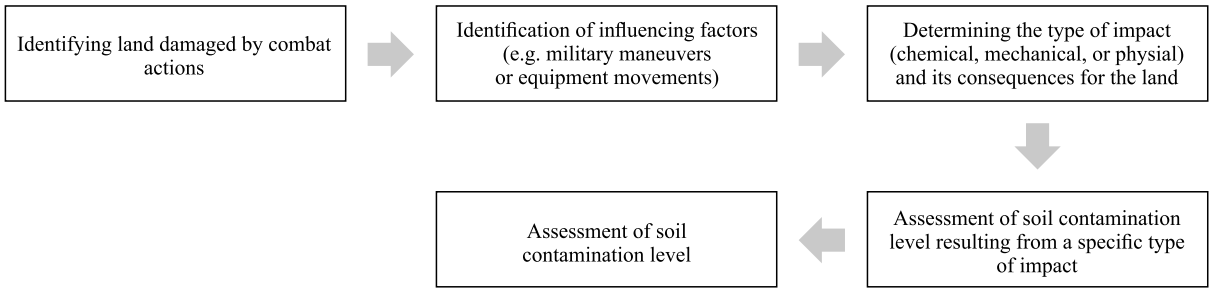

Fig. 5. Analysis of the consequences of hostilities
Source: own elaboration based on Is it possible to… (n.d.).

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deformation during the movement of wheeled and tracked military equipment, troop movements, construction of aboveground and underground structures, bombing, demining of territories, and erection of defensive infrastructure. This impact is accompanied by chemical soil contamination, leading to prolonged land withdrawal from use and restrictions on their utilization.

The primary impact of movement on soil is compaction with damage to the humus horizon, which has direct negative consequences such as disruption of the soil's water balance and causes the development of wind and water erosion. The destruction of soil structure due to the movement of tracked and wheeled machinery occurs as one layer of particles shifts relative to another under load, resulting in a loss of cohesion between particles and leading to complete destruction of the soil structure. In the reclamation of areas prone to landslides, waterlogging, and soil subsidence, it is crucial to consider the depth of groundwater, soil moisture conditions, use appropriate materials and strengthening methods, and design effective drainage systems to ensure stability and safety in construction.

It should be noted that predicting the behavior of pollutants in the soil cover is a challenging task since soil is a complex colloidal-dispersed system. It accumulates pollutants and redistributes them under the influence of military-technogenic factors, followed by translocation into trophic chains (soil-plant-human) (Sploditel et. al., 2023).

The mobilization mechanism of pollutants in soil largely depends on the formation of organic complexes, as complexation changes the bioavailability and solubility of the substances themselves. Complexation also alters the existing forms of soil pollutants, thereby changing their bioavailability and solubility. However, understanding the types of damage, including physical destruction and ecological consequences, allows for effective restoration planning. This also considers public safety, minimizing health risks. Ultimately, such analysis helps optimize resource use, ensuring the economic feasibility of reclamation measures.

CONCLUSIONS

The destructive consequences of military actions, with each conflict, weaken natural resources, which can lead to disasters and ecological crises. Land resources are among the most affected due to constant shelling, mining, pollutant leaks, and changes in morphological composition. These problems create difficulties for agriculture, industry, transportation, and, in some cases, even threaten survival. Activity in these areas has led to population migration, destruction of fertile soil layers, and the threat of famine. It is important to note that the impact on all elements of the natural environment reduces the possibility of effective societal development in the civilized world. This underscores the necessity for humanity to pursue a path of coexistence without resorting to military conflicts. Based on analysis, the negative environmental and economic consequences of military actions can be grouped and possible practical solutions for overcoming them can be formulated.

1. Soil and Water Pollution:
   a. The necessity to implement and adhere to strict international standards for assessing and rehabilitating contaminated areas post military operations is crucial.
   b. Collaboration with international organizations to secure financial and technical assistance is important.
   c. Establishment of specialized laboratories for monitoring the condition of soils and water, along with conducting regular pollution analyses.
   d. Utilization of bioremediation technologies for restoring contaminated lands.
2. Changes in Biogeochemical Balance of the Area:
   a. Development and implementation of programs aimed at restoring the biogeochemical balance, including support for biodiversity and land reclamation.
   b. Implementation of ecosystem restoration projects, including planting local plant species that contribute to natural balance restoration,

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and monitoring changes in the biogeochemical composition of territories.

3. Destruction of Water, Electric, and Gas Facilities:
   a. Implementation of infrastructure restoration programs considering ecological standards and resilience to potential future conflicts.
   b. Repair and modernization of water, electric, and gas networks using advanced technologies that minimize environmental impact.
   c. Implementation of alternative energy systems to reduce dependence on traditional sources.
4. Destruction of forests and agricultural lands:
   a. Introduction of restoration to restore ecological balance and ecosystem productivity disrupted by anthropogenic influences through reclamation and land rehabilitation. The most acceptable methods for restoring damaged areas affected by short-term military events include soil amelioration and conservation. Moderately damaged and undisturbed areas require improvement through greening and restoration of recreational areas.
   b. It is advisable to conserve and afforest lands affected by the consequences of military actions over a certain period of time. Methods for restoring areas damaged by explosions and having deep craters include filling with soil mass considering that the soil layer sequence should be close to natural, with the upper layer (20–30 cm) being the most fertile. Another method could be natural restoration or afforestation, as the absence of vegetation cover in these areas increases their erosion risk.
   c. Implementation of forestry restoration work and adoption of sustainable agricultural practices, as well as creation of incentives for farmers and agribusinesses engaged in ecological agriculture.
   d. Utilization of modern agro-technologies for soil fertility restoration.
5. Destruction of nature and animals in protected areas:
   a. Ensuring protection of protected areas from military actions and developing plans for their restoration after conflicts.
   b. Restoring damaged protected areas through reintroduction of local species.
   c. Restoring natural habitats and implementing measures to protect biodiversity.

Military actions have unpredictable environmental consequences that persist for years after conflicts end. War has caused numerous problems in Ukraine, including soil degradation and contamination. However, before reclaiming these lands, an analysis for pollutants is essential. Without such analysis, it is impossible to determine how these areas can be cleansed. Yet, due to the prolonged duration of military operations, researching all contaminated lands is currently unfeasible. For territories still experiencing active combat, the immediate priority should be landmine clearance. Therefore, at this stage, it would be prudent to establish a theoretical and legislative framework for future land restoration. To mitigate the impact of warfare on Ukraine's nature, particularly agricultural lands, comprehensive measures are necessary. These include demining territories and agricultural fields, restoring soil quality indicators, forests, and green zones, and implementing a comprehensive ecological monitoring system. Today, assessing the impact of military actions on large territories is possible with satellite technology. Such steps will promote economic and ecological stabilization in liberated areas, create conditions for the development of the economic sector and industrial production, restore Ukraine's natural resource potential using modern innovative technologies, and improve the overall health of Ukrainians, creating a comfortable living environment.

Given the complexity and multifaceted nature of the problems arising from military actions, it is necessary to combine efforts of the government, civil organizations, international institutions, and local communities. Implementing a systemic approach to addressing environmental and socio-economic issues is critically important for the stabilization and development of post-conflict territories. This includes developing and implementing legislative initiatives, international cooperation, and active participation of local communities in the restoration and development of their regions.

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