DOI https://doi.org/10.30525/978-9934-26-570-9-43

MILITARY ACTIONS AS A THREAT TO LAND RESOURCES: DAMAGE ASSESSMENT AND ECOLOGICAL REHABILITATION MECHANISMS

Novakovska I. O., Ishchenko N. F., Skrypnyk L. R.

INTRODUCTION

Military operations pose one of the greatest threats to land resources, causing their degradation, pollution and loss of economic value. Intense hostilities, explosions of ammunition, the use of heavy equipment and the deliberate destruction of infrastructure lead to serious changes in the structure of the soil, the destruction of the fertile layer, pollution with chemicals and disruption of the hydrological regime of the territories. The consequences of such changes are long-term and threaten not only the ecological balance, but also the economic development of regions, which largely depends on the use of land resources.

In Ukraine, as a result of the full-scale invasion, significant areas of agricultural land and natural areas have been contaminated with munitions, chemicals and heavy metals, which poses a threat to food security and the ecological stability of the regions. In the context of post-war reconstruction, there is an urgent need for a comprehensive assessment of the damage caused and the development of effective mechanisms for the ecological rehabilitation of land resources.

This includes demining of territories, soil reclamation, the introduction of environmental technologies and measures to restore land productivity. An important aspect is the integration of these mechanisms into the state land use policy, which will contribute to ensuring sustainable development and increasing the country's ecological security.

Thus, studying the problem of the impact of military actions on land resources, assessing environmental damage, and finding optimal ways to restore them is extremely relevant for Ukraine in the context of post-war reconstruction and ensuring the ecological sustainability of territories.

1. Impact of military operations on land resources

Land resources are one of the key elements of the environment, ensuring food security, ecological balance and economic stability of society. However, in war zones they are exposed to serious threats that can have long-term consequences for the environment and socio-economic development of regions. The main threats to land resources in such conditions can be divided into several categories. (Fig. 1)

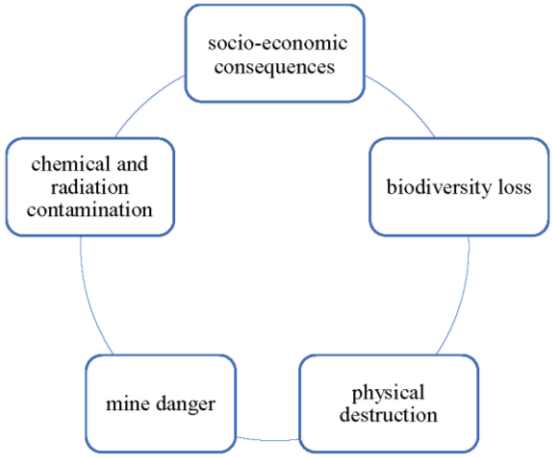

Fig. 1. Main threats to land resources in conditions of hostilities

One of the most noticeable consequences of hostilities is mechanical damage to the land cover. Ukraine is a large agrarian country and a significant part of our economy is the production and export of agricultural products.

According to the State Geocadastre of Ukraine, as of January 1, 2022, the land fund of Ukraine is 60.355 million hectares (Fig. 2.), of which 68.5% (41.3 million hectares) are agricultural lands, 17.7% (10.7 million hectares) are forests and other forest-covered lands, 6.2% (3.8 million hectares) are built-up lands, 4.0% (2.4 million hectares) are lands under water, 1.6% (1.0 million hectares) are open wetlands.[1]

Ukraine is one of the countries with high land arable land. Agricultural lands occupy 70.5% of the total area of the country, of which 57% is arable land (in some regions – up to 86%).[2] Shell explosions, construction of trenches, trenches and other fortifications destroy the soil layer, change the natural relief and contribute to erosion processes. The affected areas often turn into infertile or even unsuitable for further land use. Thousands of fired shells, blown up and burned military equipment abandoned in fields and plantings are a significant and long-lasting source of pollution of our soils and groundwater with iron, aluminum, copper, other heavy metals and their compounds for hundreds of years. (Fig. 3)

[1] Статистичний щорічник України за 2021 рік. https://www.ukrstat.gov.ua/druk/publicat/kat_u/ 2022 /zb/ 11/ Yearbook_2021.pdf

[2] Україна має найвищий відсоток розораності земель в світі. https://agronews.ua/news/ukrayina-maye-najvyshhyj-vidsotok-rozoranostizemel-v-sviti/

The main mechanical impact on the soil is compaction with damage to the humus layer, which has direct negative consequences, such as disruption of the soil water balance, and causes the development of wind and water erosion.

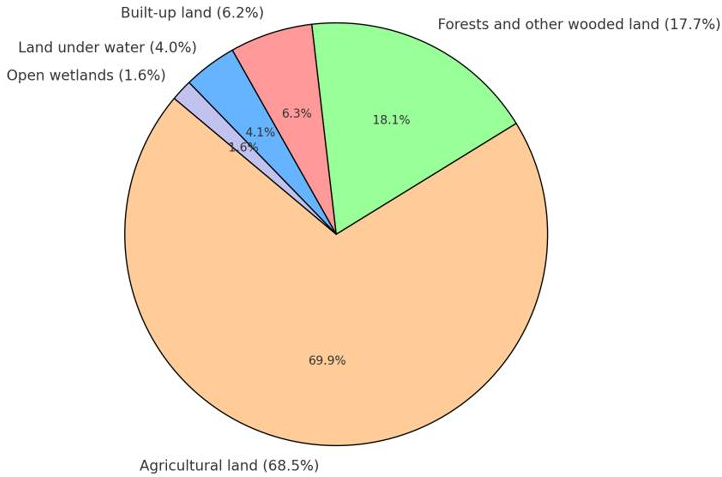

Fig. 2. Distribution of land by categories as of January 1, 2022

Fig. 3. Consequences for land resources: destruction and pollution [2]

The destruction of the soil structure occurs as a result of the displacement of particles of one layer relative to another under the influence of military-technogenic loads. More than 15 million hectares of land are under the influence of military operations, where soil degradation processes and soil

cover destruction are widespread. Almost all types of soils have been affected, with black soil being the most affected type of soil. More than 5 million hectares of black soil have been in the combat zone at different times, which has led to their military degradation of varying intensity and direction.[3]

Analysis of the results of soil sample measurements (organic carbon, salt pH, exchangeable cations, soil particle size distribution) revealed changes in the soil cover of the areas affected by equipment in terms of organic carbon, as well as the particle size distribution in areas where equipment was burned. It was found that the mechanical impact of military equipment, especially in areas where it was burned, increases the variegation of the soil field, which must be taken into account during future cultivation and fertilizer application. The authors of study 4 consider this aspect using the example of a fragment of the results of determining the content of exchangeable cations, organic carbon, and salt pH in soil samples that were affected by hostilities in the Chkalovsk community. (Table 4)

Table 4

Analysis of the impact of hostilities on the soil (using the example of the territory of the Chkalovsk community of the Kharkiv community)[4]

Title of Heavy Machinery, Sampling Depth (cm)	Ca^{2+}	Mg^{2+}	Na	K	∑	Organic Matter Carbon (%)	pH (Saline)
Background, Combine, 0-30	25.42	3.99	0.15	0.77	30.33	3.3	5.06
Background, Combine, 30-60	25.68	3.32	0.15	0.51	29.66	2.77	5.34
Debris, Combine, 0-30	24.94	3.32	0.18	0.66	29.1	3.25	5.1
Debris, Combine, 30-60	24.23	2.85	0.18	0.65	27.91	2.77	5.45
Background, BM-21, 0-30	30.52	3.99	0.15	0.85	35.51	3.27	6.84
Background, BM-21, 30-60	32.71	4.53	0.13	0.71	37.98	2.05	6.84
Debris, BM-21, 0-30	31.43	4.53	0.15	0.68	36.79	2.63	6.21
Debris, BM-21, 30-60	30.05	3.99	0.15	0.63	34.82	2.26	6.51
Background, Tank, 0-30	26.38	3.99	0.15	0.72	31.24	2.46	5.96
Background, Tank, 20-30	25.32	3.32	0.15	0.55	29.34	1.36	6.31

[3] *С. Балюк, А. Кучер, М.Солоха.* Оцінка впливу війни на чорноземи як передумова відновлення їхньої родючості.2024. URL: https://agroportal.ua/blogs/ocinka-vplivu-viyni-na-chornozemi-yak-peredumova-vidnovlennya-jihnoji-rodyuchosti

[4] С. Балюк, А. Кучер, М.Солоха. Оцінка впливу війни на чорноземи як передумова відновлення їхньої родючості.2024. URL: https://agroportal.ua/blogs/ocinka-vplivu-viyni-na-chornozemi-yak-peredumova-vidnovlennya-jihnoji-rodyuchosti

Background, Tank, 30-40	25.29	3.32	0.15	0.45	29.21	1.37	6.41
Background, Tank, 50-60	-	-	-	-	-	-	-
Debris, SPG, 0-30	30.52	3.81	0.18	0.9	37.32	3.27	6.51
Debris, SPG, 30-60	29.45	3.53	0.18	0.5	33.67	3.64	6.98
Background, SPG, 30-60	-	-	-	-	-	1.24	7.21

Analysis of the condition of soils in agricultural fields affected by military operations confirmed the presence of significant changes in their composition and structure. The remains of armored vehicles remaining on arable land lead to an increase in the content of heavy metals, which creates risks for the environment and agricultural production. At the same time, the removal of these debris contributes to the stabilization of the situation and the restoration of land suitability for use.

The physicochemical characteristics of the soils have also undergone transformations, especially in areas of damage – under debris of equipment and in explosion craters. However, observations show that due to the natural buffering of chernozems, their resistance to external influences remains high, and significant deterioration of the structure has not yet been recorded.

The dynamics of changes in the content of organic carbon turned out to be interesting. In the first years after the ignition of oil products, its sharp increase was observed, but over time this indicator stabilized. This is especially noticeable on chernozems, where the activation of microbiota contributes to a faster restoration of the natural balance.

Given the scale of changes, the soil cover was zoned according to the level of degradation and a program for the accelerated restoration of chernozems was developed. It provides for a set of measures to restore fertility and ensure the ecological safety of agricultural landscapes, which is an important step towards the revival of agricultural lands after the impact of the war.

Combat operations are accompanied by the use of various explosives and chemicals that enter the soil and groundwater, causing serious environmental consequences. Explosives contained in artillery shells, missiles, mines and air bombs, when decomposed, form toxic compounds that penetrate the environment. Ammunition fragments, explosive residues, petroleum products and heavy metals, in particular lead, mercury, cadmium, copper and zinc, accumulate in the ground, changing its physicochemical properties and making it unsuitable for agricultural use.

In modern armor-piercing subcaliber shells, the armor-piercing part (core) is most often made of depleted uranium. The use of this metal is associated

with its physical properties – the ability to self-ignite and burn as a result of contact with armor and its penetration.[5]

The use of depleted uranium in armor-piercing shells has a significant impact on soils, especially in areas of active combat. (See Fig. 4)

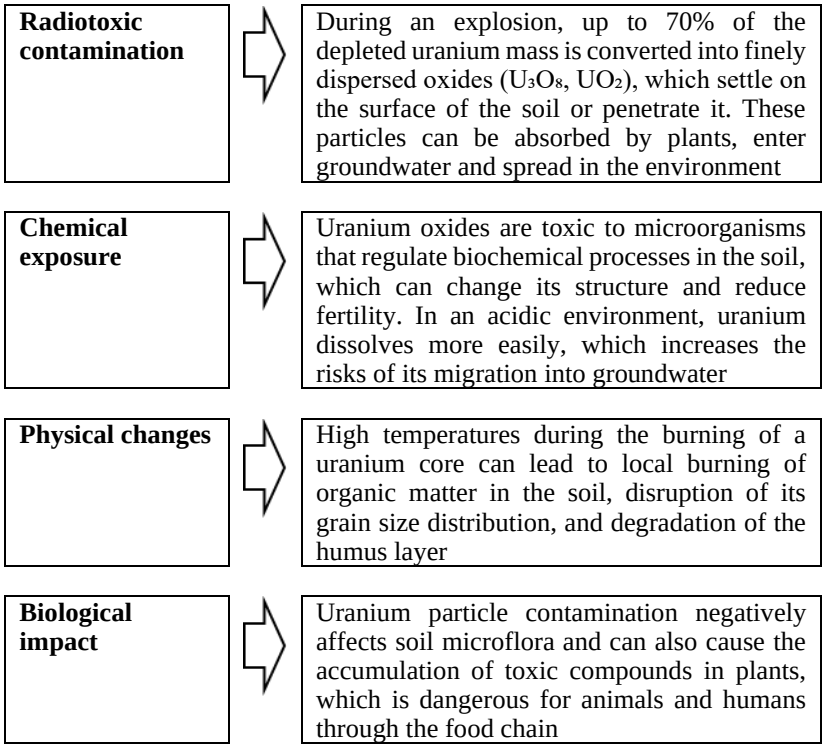

Fig. 4. Consequences of the use of depleted uranium in ammunition in the context of the threat to the environmental security of regions where military conflicts occur

At the same time, small fragments of the uranium core of the projectile spread and contribute to the burning of combustible materials or the detonation of ammunition inside the object being hit. Almost up to 70% of the entire mass of depleted uranium contained in the projectile burns out and

[5] О. Ангурець, П. Хазан, К. Колесникова, М. Кущ, М. Чернохова, М. Гавранек. Наслідки для довкілля війни росії проти України. 2022. 84 с. URL: https://cleanair.org.ua/wp-content/uploads/2023/03/cleanair.org.ua-war-damages-ua-version-04-low-res.pdf

turns into an aerosol of radiotoxic uranium oxides (U3O8, UO2) with particles from 0.5 to 5 microns during the explosion.

The combustion or utilization of ballistic rocket fuels used in MLRS (such as "Hurricane", "Grad", etc.) is accompanied by the formation of a number of toxic components: CO, HCN, NO, NO2, etc. Lead in the combustion or explosion products of solid rocket fuel is present in the form of aerosols of lead and its oxide PbO.

In general, the combustion or utilization of solid rocket fuel leads to the formation of: CO up to 416.2 g/kg, C up to 86.4 g/kg, Pb up to 6.7 g/kg, PbO up to 1.8 g/kg, NO up to 161.6 g/kg, NO2 up to 2.9 g/kg, CH4 up to 55.0 mg/kg, NH3 up to 0.3 g/kg, HNO2 up to 0.4 g/kg, HCN up to 5.2 g/kg.[5]

Depleted uranium munitions, used to penetrate armored targets, are particularly dangerous. Their decay releases radioactive particles that can remain in the environment for decades, contaminating soil and water. (Fig. 5.)

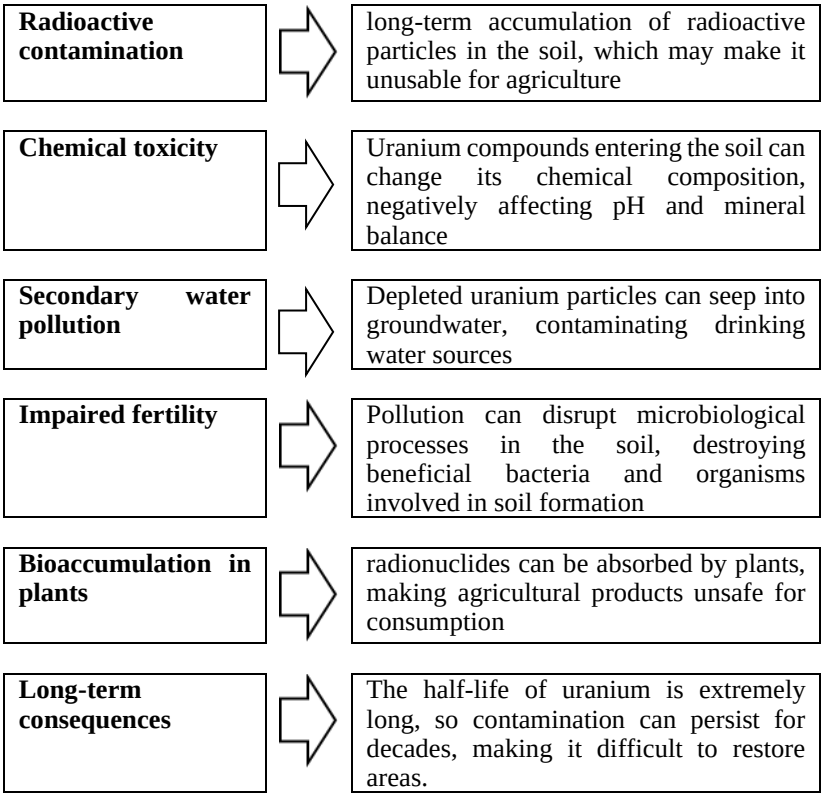

Fig. 5. Possible consequences of using depleted uranium ammunition for soil

Radioactive contamination poses a threat not only to plants and animals, but also to humans, as it can cause cancer, disruption of internal organs, and genetic mutations. In addition, fires often occur in ammunition depots, fuel and lubricants depots, and chemical plants in war zones, which causes additional release of toxic substances into the air, water, and soil.

All of these factors significantly affect ecosystems, reducing soil fertility, contaminating water resources, and increasing morbidity among the population.

Another challenge of war in terms of land use is the mine hazard and explosive remnants of war. Unexploded ordnance, mines, cluster munitions, and other explosive devices pose a serious threat to land use. The large number of such remnants makes it impossible to safely use the territories for agriculture, forestry, or construction. The territory of Kharkiv Oblast, for example, requires thorough demining work, as the occupiers have been there for more than six months.[4] (Fig. 6)

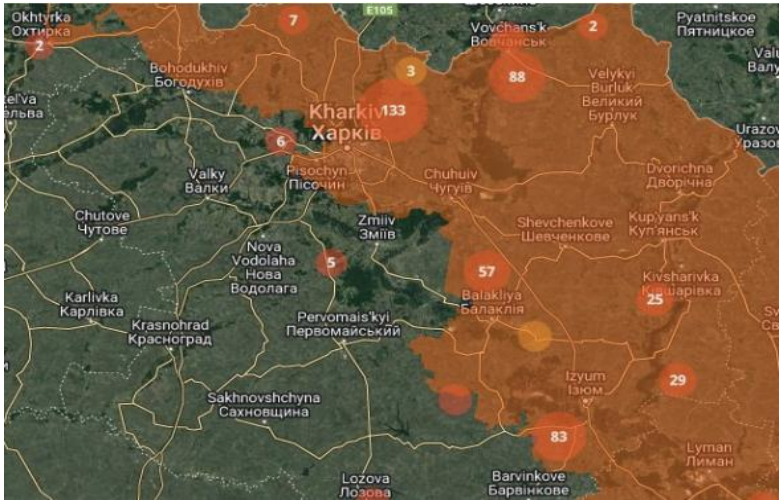

Fig. 6. Map of areas around Kharkiv that could potentially be contaminated with explosives [6]

The indicated map shows the locations where explosives have already been detected or are likely to be located, and the degree of threat from them according to the information available to the State Emergency Service (the

[6]Рачков С.М. Методичні рекомендації «Правила поводження з вибухонебезпечними предметами», 2023. Харків. URL: https://nmc.dsns.gov.ua/upload/3/8/1/4/5/metodicka-pravila-povodzennia-z-vnp.pdf

localization error is up to 30 m). At the same time, the demining process takes a lot of time and requires significant financial resources.

Military actions cause the destruction of natural ecosystems. Mass fires, the destruction of forest areas and water resources lead to the loss of biodiversity. The destruction of ecosystems affects not only wild species of animals and plants, but also the restoration of soil cover, which can take decades.

As of November 2022, more than 3 million hectares of forests have been damaged as a result of military operations, which is almost a third of Ukraine's forest fund. As a result of the fire in the Kherson National Park in 2022 alone, about 80% of the island part of the territory burned down, and the fires in the Chernobyl forests could not be extinguished for several days due to the occupation of the territory. It takes about 10 years to restore the forests, but some of them are lost forever. It is worth noting that many bird migration routes pass through Ukraine, many animals from the Red Book live in protected areas, so they can die due to fires.[7]

As a result of Russia's full-scale military aggression against Ukraine, many species of animals and plants are on the verge of extinction. In particular, 333 species of plants and animals are under threat of extinction due to the explosion of the Kakhovka hydroelectric power station dam (149 rare Danube newts died as a result of the explosion, 55 newts were rescued), 900 dolphins died in the Black and Azov Seas due to the use of sonar by Russian ships, some Red Book animals are on the verge of extinction due to constant hostilities in their habitats, 20 species of plants that grow exclusively in Ukraine are under threat of extinction.

Oil spills from attacks on infrastructure kill fish, seabirds, and microorganisms. Forest fires cause damage to biodiversity and protected areas, which in peacetime are caused in 83% of cases by careless fire management, and during wartime by shelling and bombing. In particular, in 2022-2023, 183.2 thousand hectares of forests and other plantations were burned.

According to the State Agency of Forest Resources of Ukraine, due to the consequences of military operations, the number of forest fires increased tenfold compared to the previous year. The area of fires increased almost 100 times. The worst situation is in the South, in particular in the Kherson region, and in the East of Ukraine. Luhansk, Donetsk, Zaporizhia, and Mykolaiv regions suffer. There, literally a thousand hectares of forest burn down per day. These are man-made forests, which are 15–20 years old, and are very difficult to grow.

[7] Війна та екологія: чому природа стає жертвою збройного конфлікту? 2023. URL: https://iaa.org.ua/articles/vijna-ta-ekologiya-chomu-pryroda-staye-zhertvoyu-zbrojnogo-konfliktu/Ртрпоророороо

According to the Mykolaiv Regional Department of Forestry and Hunting, on June 3-4, a fire on the Kinburn Spit destroyed approximately 300 hectares of protected areas. The fire was extinguished in extremely difficult conditions, mainly by local residents with the involvement of their own equipment and forestry. The extent of the damage is currently difficult to assess, but it is significant. Areas of forest ecosystems were lost, rare species of animals and the unique sandy flora of Kinburn were destroyed and damaged. Kinburn Spit is of international environmental importance, as it is an object of the Emerald Networki. [8]

The destruction of land resources in war zones leads to serious socio-economic problems. The loss of fertile land reduces the food security of the regions, which complicates the restoration of the agricultural sector. Many territories become uninhabitable, which causes population migration and a decrease in the investment attractiveness of the regions.

2. Assessment of damage from military operations

Military conflicts always cause significant losses for the state and society. Cities and villages are destroyed, infrastructure is destroyed, the economy suffers, the ecological situation worsens, and most importantly, human lives are lost. (Fig. 7)

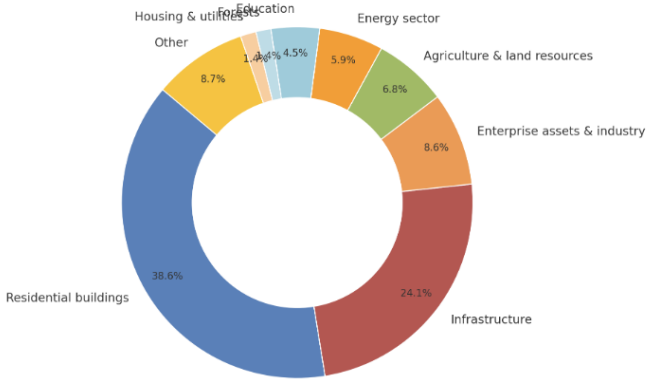

Fig. 7. Direct losses from destruction and damage by sectors, $ billion

Since the beginning of the full-scale Russian military invasion, the total direct damage to residential and non-residential real estate, other

[8] Дайджест ключових наслідків російської агресії для українського довкілля за 2-8 червня 2022 року. URL: https://mepr.gov.ua/dajdzhest-klyuchovyh-naslidkiv-rosijskoyi-agresiyi-dlya-ukrayinskogo-dovkillya-za-2-8-chervnya-2022-roku/

infrastructure, vehicles and inventories has exceeded $157 billion (at replacement cost). In June 2023, the explosion of the Kakhovka hydroelectric power station caused at least $2 billion in direct damage. (Table 2) The main sectors affected by this terrorist attack in terms of direct damage estimates are: housing (direct damage – $1.03 billion), energy ($586 million), transport infrastructure ($311 million), industry ($105 million), agriculture ($25 million).[9]

Table 2

Assessment of direct losses to the agricultural sector and land resources[10]

Types of Losses	Unit of Measurement	Initial Number of Objects	Number of Damaged Objects	Estimated Losses, $ billion
Destroyed				
Agricultural machinery	units	764,323	130,603	5.43
Grain storage capacity	thousand tons	75,084	11,351	1.7
Dead animals (including poultry and fish farming)	thousand heads	203,292	1,899	0.1
Destroyed beehives	beehive colonies	2,272,740	86,902	0.1
Perennial crops	ha	197,100	16,364	0.4
Destroyed and stolen production factors	tons	962,951	135,993	0.1
Destroyed and stolen finished agricultural products	tons	254,866,13	4,037,542	1.9
Aquaculture and fisheries facilities	units	2,102	228	0.03
Damaged				
Animal slaughter due to inability to maintain	thousand heads	203,292	11,963	0.1
Dead and missing bees	beehive colonies	2,272,740	192,526	0.0
Agricultural machinery	units	764,323	50,521	0.4
Grain storage capacity	thousand tons	75,084	3,341	0.1
Total Direct Infrastructure Losses	x	x	x	10.3

[9] Війна та екологія: чому природа стає жертвою збройного конфлікту? 2023. URL: https://iaa.org.ua/articles/vijna-ta-ekologiya-chomu-pryroda-staye-zhertvoyu-zbrojnogo-konfliktu/Ртрпоророоpoo

[10] Звіт про прямі збитки інфраструктури від руйнувань внаслідок військової агресії Росії проти України станом на початок 2024 року. URL: https://kse.ua/wp content/uploads/ 2024/04/01.01.24_Damages_Report.pdf

Table 2. reflects the significant losses in agriculture caused by destruction and damage to infrastructure, machinery, livestock and product stocks. The largest financial losses are associated with the loss of agricultural machinery, granaries and finished products, which complicates the recovery of the agricultural sector. Significant losses among livestock and bees indicate a crisis in livestock and beekeeping. The total amount of direct infrastructure losses is $ 10.3 billion, which emphasizes the need for rapid measures to support farmers, restore storage facilities and ensure the sustainable functioning of the agro-industrial complex.

The mechanism for determining military losses, which include human and material military losses and expenses associated with combat operations (terrorist acts, sabotage, missile and bomb strikes) caused by the military aggression of the Russian Federation, is established by the Methodology for Determining Military Losses. According to it, the assessment of losses is carried out by conducting an analytical assessment of losses, a standardized, independent assessment of losses, or is the result of a forensic examination. The calculation is carried out on the basis of a decision of the Ministry of Defense. [11]

The initial data used during the assessment of losses are:

legal, technical and other documentation on the property that has been subjected to destructive effects, which allows its identification;

the results of a standardized or independent assessment of damage and losses contained in the Register of Damaged and Destroyed Property;

the results of an inspection of the object of assessment, carried out, in particular, using technical means and information sources (photographic materials, video materials, geospatial data, digital cartographic materials, remote sensing data of the Earth and their derivatives, social network analytics, existing public information, etc.);

market data used during the assessment of losses: information on purchase and sale transactions of property similar to the object of assessment, market prices for similar property, etc.;

other information sources that can be used during the assessment of losses, determined by the methods of assessing damage and losses.

The procedure for calculating the amount of damage caused to land and soil by states, executive authorities, local governments, business entities and individuals due to soil pollution, land contamination caused as a result of emergencies and/or armed aggression and hostilities during martial law as a result of their actions or inaction on all lands of Ukraine, regardless of their categories and forms of ownership, is determined by the methodology approved by the order of the Ministry of Environment of 04.04.2022. [12]

---

[11] Про затвердження Методики визначення військових втрат, завданих Україні внаслідок збройної агресії Російської Федерації: наказ Міністерства оборони України від 14.09.2022 р. № 277. URL: https://zakon.rada.gov.ua/laws/show/z1471-22#Text

[12] Про затвердження Методики визначення розміру шкоди завданої землі, ґрунтам внаслідок надзвичайних ситуацій та/або збройної агресії та бойових дій під час дії

According to the specified methodology, the amount of damage from soil contamination is determined by formula (1):

$$RSh = A \times GOZ \times PD \times KN \times Ko + Vr, \quad (1)$$

where:

RSh – the amount of damage caused by soil pollution, UAH;

A – specific costs for eliminating the consequences of soil pollution for the respective land plot, with a value of 1.5;

GOZ – the normative monetary valuation of the land plot whose soil has been polluted, UAH/sq. m;

PD – the area of the land plot whose soil has been polluted, sq. m;

KN – the hazard coefficient of the pollutant;

Ko – the coefficient applied to account for the environmental value of the land plot;

Vr – the cost of land reclamation for areas polluted due to emergencies and/or military aggression and hostilities during the period of martial law, calculated using the following formula:

$$Vr = K(s) \times K(k) \times K(z) \quad (2)$$

where:

Vr – the cost of land reclamation;

P1 – the base cost;

P2 – the cost based on area;

K(s) – the complexity coefficient;

K(k) – the coefficient representing the number of polluted/contaminated plots within a single territorial community;

S – the area of land plots with polluted soil;

K(z) – the coefficient for land restoration work;

K(z) – the coefficient for land restoration work, calculated as (P1 + P2) × S (Table 3).

Table 3

Coefficient of earthworks

#	S – Area, ha	P1 – Base Cost, UAH	P2 – Cost per Area, UAH/ha
1	Up to 5	25000	4000
2	From 5 to 10	30000	4000
3	From 10 to 20	35000	4000
4	From 20 to 50	40000	4000
5	From 50 to 100	45000	4000
6	Over 100	50000	4000

Complexity factor K(c): for flat terrain, the factor is 1, in other cases – 1.2.

воєнного стану: наказ Міндовкілля України від 04.04.2022 р. № 167. URL: https://zakon.rada.gov.ua / laws /show/z0406-22#Text

When developing a reclamation project covering several contaminated/contaminated land plots, the factor K(k) is used (Table 4)

Table 4

Coefficient for developing a reclamation project for several contaminated/contaminated land plots

Number of plots	Coefficient of the number of sections K(k)
1	1
2	1,1
3	1,2
4 or more	1,9

The total amount of compensation for simultaneous contamination of a land plot with several pollutants is determined by formula (3):

$$Rsh.total = Rsh.max + 0.5 \times (Rsh1 + Rsh2 + \cdots + Rshn) \quad (3)$$

where:

Rsh.total – total damage caused by the contamination of a land plot by multiple pollutants, UAH;

Rsh.maxR_{sh.max}Rsh.max – the maximum damage among those calculated separately for each pollutant, UAH;

Rsh1+Rsh2+⋯+RshnR_{sh1} + R_{sh2} + \dots + R_{shn}Rsh1+Rsh2 +⋯+Rshn – the calculated damage caused by the contamination of the land plot by other pollutants, UAH.

The amount of damage due to land contamination is determined by the formula:

$$Rshz = A \times B \times Goz \times Pdz \times Kzz \times Keg, \quad (4)$$

Where:

Rshz – the amount of damage caused by land pollution, UAH;

A – specific costs for eliminating the consequences of land pollution, including cleaning, with a value of 1;

B – conversion coefficient, which equals 15 in cases of land pollution with foreign objects, materials, waste, and/or other substances without proper permits, and 300 for hazardous waste and/or other hazardous substances.

Goz – normative monetary valuation of the polluted land plot, UAH/sq. m;

Pdz – area of the polluted land plot, sq. m;

Kzz – land pollution coefficient, characterizing the degree of pollution by waste;

Keg – ecological and economic significance coefficient of the land.

Economic assessment of damages and costs of land restoration is an important tool for developing effective land management policies. (Fig. 8)

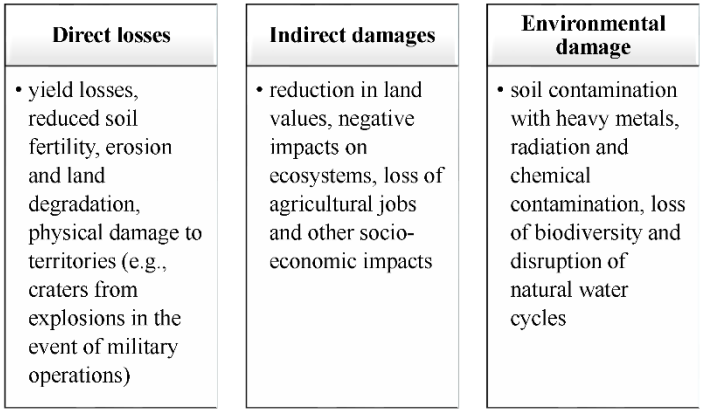

Fig. 8. Key aspects of economic assessment of damage caused to land resources

Various valuation methods are used to determine the economic value of losses, including the market approach (estimation of yield losses and land value), the cost approach (calculation of necessary restoration costs) and the ecosystem services approach (determination of losses to the environment). [13]

Crop losses can have both local and global consequences, affecting not only the economy of the agricultural sector, but also the overall stability of the food market. The assessment of such losses is based on a careful analysis of actual production indicators and their comparison with optimal or historical data. [14]

According to the report on agricultural losses, losses and needs due to the full-scale invasion, the total losses in this sector in the two years after the

[13] В. Ладиченко, Н. Мединська, І. Новаковська, Б. Яринко Правові аспекти захисту земель як національного багатства України в умовах агресії: міжнародні та національні підходи. Національні інтереси України. № 3 (3). 2024. Сс 210-224 https://doi.org/10.52058/3041-1793-2024-3(3)-210-224

[14] Мединська Н.В., Новаковська І.О., Близнюк В.В. Вплив рентних платежів на природокористування: аналіз економічних й екологічних аспектів сьогодення та в період післявоєнного відновлення. Актуальні питання у сучасній науці № 6(24) 2024. Сс. 118-131. https://doi.org/10.52058/2786-6300-2024-6(24)-118-130

invasion are $ 10.3 billion. [15] The distribution of losses by category is presented in Figure 9.

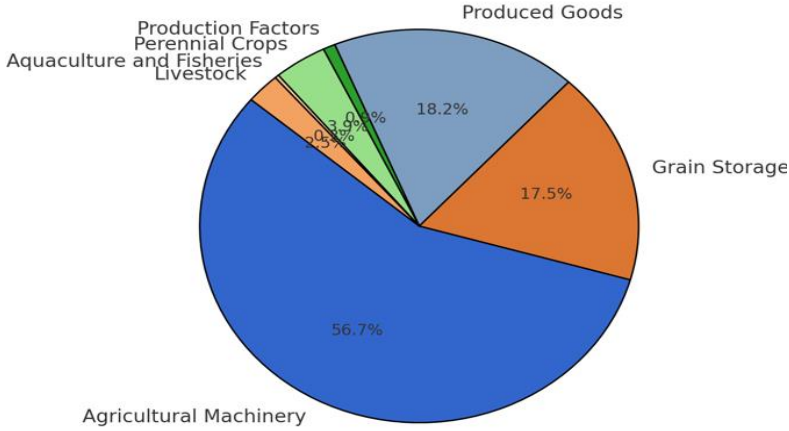

Fig. 9. Distribution of losses by category

Analysis of the structure of the agricultural sector shows that the main emphasis is on the mechanization of production (56.7%), which contributes to increasing the efficiency of agricultural activities. A significant share of granaries (17.5%) and produced products (18.2%) indicates the importance of infrastructure for storing and processing agricultural products. At the same time, perennial plantings (3.9%), livestock (2.5%), production factors (0.9%) and aquaculture (0.3%) have a less significant impact, which may indicate insufficient attention to these areas. This indicates opportunities for diversification of agriculture and increased investment in less developed sectors. In addition to losses due to damage and destruction of physical assets, Ukrainian agricultural producers face indirect losses caused by loss of income due to reduced production, lower prices and increased production costs.

Unlike the losses localized to the territories affected by military actions, indirect losses are suffered by farmers throughout Ukraine. The total estimated indirect losses amount to 69.8 billion dollars. (Fig. 10)

[15] Р. Нейтер, С. Зоря, О.Муляр. Збитки, втрати та потреби сільського господарства через повномасштабне вторгнення. 2024. 33 с. URL: https://kse.ua/wp-content/uploads/2024/02/RDNA3_ukr.pdf

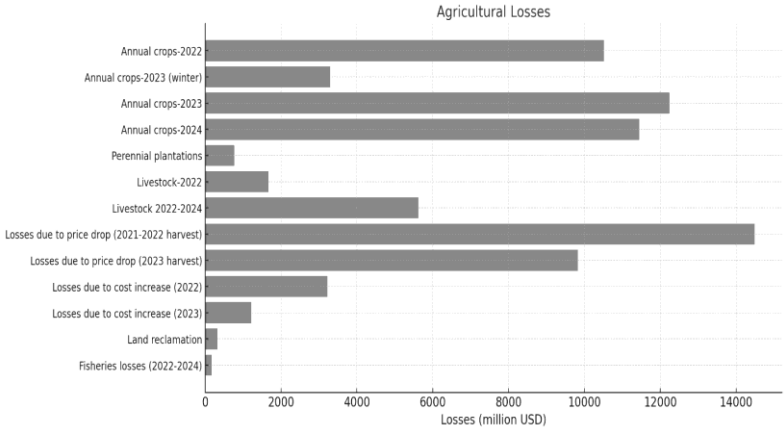

Fig. 10. Current assessment of losses in agricultur [15]

The data in Figure 10 indicate significant economic losses in the agricultural sector due to reduced production, falling prices, increased production costs, and other factors. The largest losses were suffered by annual crops (especially in 2023 – $12.245 million) and losses due to lower prices for the 2021-2022 harvest ($14.480 million). Also significant are losses in livestock ($5.624 million for 2022-2024) and increased production costs. The total volume of losses in agriculture exceeds $69.7 billion, which requires effective measures to restore and support the industry.

According to the estimates of the State Ecological Inspectorate of Ukraine, the damage caused to the country's environment and ecosystems during the 500 days of warfare on the territory of Ukraine reaches a large amount, which is more than 2 trillion hryvnias. (Fig. 11)[16]

The diagram (Fig. 11) shows significant financial losses due to environmental violations. The largest losses are caused by land contamination (929.7 billion UAH), while water pollution (40.2 billion UAH) and unauthorized use of water resources (15.5 billion UAH) also have a significant impact. This emphasizes the need to strengthen environmental control and effective management of natural resources.

Given the scale of the damage and losses suffered by agricultural producers in Ukraine, the full restoration of the sector's potential requires significant resources. [17]

[16] Офіційний сайт Державної екологічної інспекції України. URL: https://www.dei.gov.ua/post/2694

[17] Офіційний сайт Державної екологічної інспекції України. URL: https://www.dei.gov.ua/post/2694

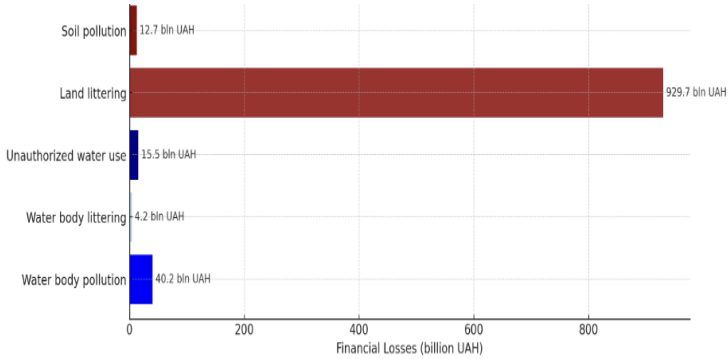

Fig. 11. Financial losses from environmental violations for the period 02/24/2022 – 07/07/2023

We distinguish two broad categories of needs – reconstruction needs and restoration needs. According to estimates by the Ministry of Agrarian Policy and Food (MAPF), other ministries, as well as statistics on allocated donor support for Ukrainian agriculture for the 2024 calendar year, the total reconstruction and restoration needs are estimated at 56.1 billion USD. They identify the resources needed to replace damaged assets that are critical to the revival of agricultural production.

Assessing damage from military operations is an important task, as it allows not only to determine the extent of destruction, but also to develop effective recovery strategies. (Fig. 12)

Damage assessment is an important step in the recovery process after emergencies, military conflicts, natural disasters and economic crises. It allows to determine the extent of losses, develop compensation and recovery strategies, as well as ensure the effective allocation of financial resources. There are several approaches to damage assessment that can be used depending on the specific situation. (Fig. 13)

At the same time, it should be noted that effective damage assessment requires a comprehensive approach that combines economic, environmental, social, legal and technological aspects. The use of modern technologies and scientific methods allows you to obtain more accurate information, which is the basis for developing effective strategies for restoration and compensation for damage. In the context of military conflict and environmental threats for Ukraine, the implementation of integrated assessment systems is relevant, which will contribute to the rapid recovery of the country and its sustainable development.

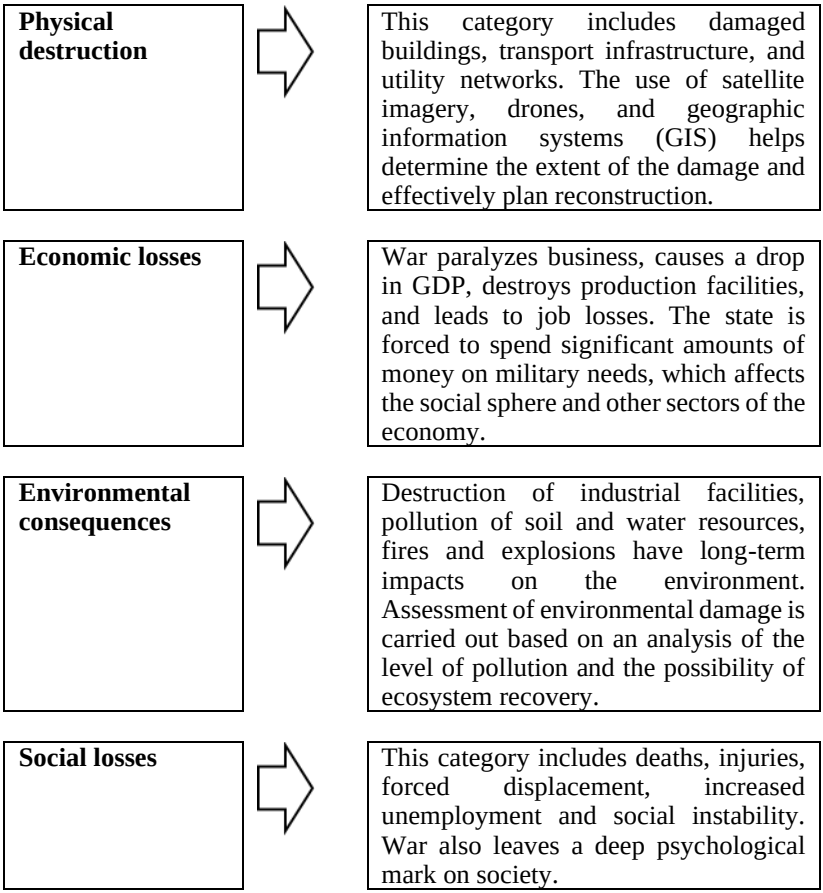

Fig. 12. Main areas of damage assessment

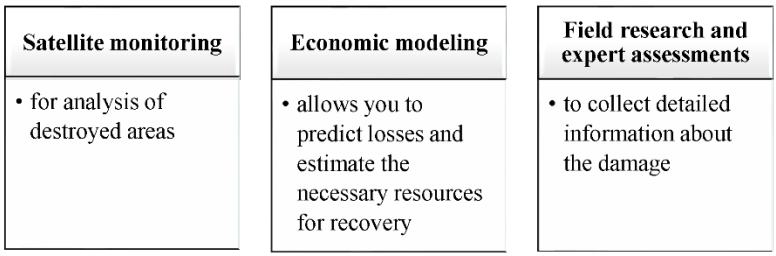

Fig. 13. Approaches for effective damage assessment

3. Mechanisms for ecological rehabilitation of land resources

Military conflicts have a devastating impact on the environment, especially on land resources. Soil contamination with heavy metals, destruction of natural landscapes, changes in the hydrological regime of territories are just some of the environmental consequences of hostilities. Land restoration is critically important for ensuring food security, economic recovery, and biodiversity conservation.

In this context, effective ecological rehabilitation requires the implementation of comprehensive mechanisms that include scientifically sound, technological and organizational measures. (Fig. 14). The scheme reflects a comprehensive approach to the rehabilitation of land resources after military operations. [18]

Fig. 14. Main mechanisms of land rehabilitation

It is structured into five key stages that logically complement each other. (Fig. 15)

Ecological rehabilitation of lands after military operations is a multifaceted process that requires a systematic approach and long-term efforts. The implementation of the proposed mechanisms will minimize the negative consequences of military operations, restore soil fertility and ensure the ecological safety of territories.

[18] I. Novakovska, N. Medynska, L. Hunko, L. Skrypnyk, V. Samsonova, N.Shevchenko.(2024) Formation of the economic mechanism of nature management in the conditions of new global environmental architectonics . Opportunities and Risks in AI for Business Development Volume 2. Pp. 313-326. https://doi.org/10.1007/978-3-031-65207-3

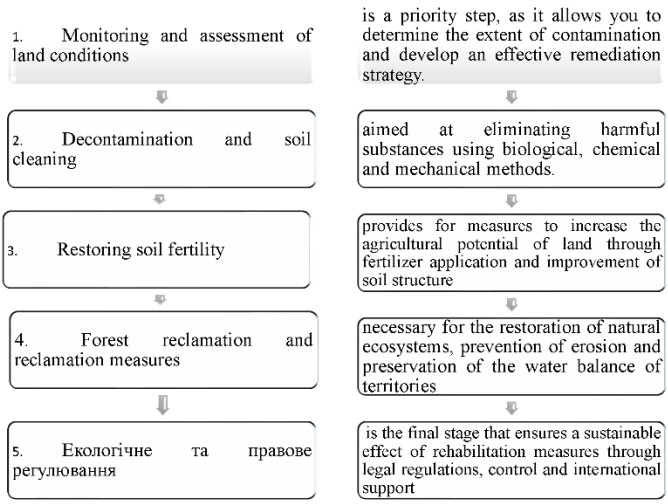

Fig. 15. Stages of a comprehensive approach to the rehabilitation of land resources after military operations

An important factor in success is intersectoral cooperation between the government, scientific institutions, environmental organizations and international partners.

To ensure effective management and restoration of degraded areas, it is necessary to apply comprehensive institutional and legal mechanisms. Institutional mechanisms include the activities of state bodies, scientific institutions, public organizations and international partners.

The main bodies that manage the field of environmental rehabilitation are the Ministry of Environmental Protection and Natural Resources of Ukraine, the State Service of Ukraine for Geodesy, Cartography and Cadastre, local governments, international organizations and donors. A significant role is played by scientific research institutes and public organizations that monitor the implementation of environmental programs. [19]

The legal regulation of ecological land rehabilitation in Ukraine is based on the Land Code of Ukraine, the Law of Ukraine "On Land Protection", the Law of Ukraine "On Environmental Impact Assessment" and the Environmental Strategy of Ukraine for 2030. In addition, international agreements ratified by Ukraine, such as the UN Convention to Combat

[19] Бавровська Н.М., Іщенко Н.Ф., Новаковська І.О. Стан і перспективи досягнення індикаторів цілей сталого розвитку в умовах воєнного стану та повоєнного відновлення. Наука і техніка сьогодні. 2025. № 1 (45). Сс. 204-216. https://doi.org/10.52058/2786-6025-2025-1(42)-204-216

Desertification and the Paris Agreement, oblige the state to implement effective land rehabilitation mechanisms.

Despite the existence of a legislative framework and institutional support, ecological land rehabilitation in Ukraine faces a number of problems, including insufficient funding for environmental programs, low efficiency in implementing legislative norms, insufficient level of coordination between state and local authorities, as well as land contamination as a result of military actions and man-made disasters.

To improve the situation, it is necessary to strengthen state control over the implementation of environmental programs, intensify international cooperation in the field of environmental rehabilitation, create effective economic incentives for land owners, and expand the use of modern technologies, in particular biotechnology and GIS systems for monitoring.

CONCLUSIONS

Military operations have a devastating impact on land resources, causing physical destruction, chemical and radiological contamination, mine hazards, biodiversity loss and socio-economic impacts. To minimize these negative effects, a comprehensive approach to recovery is needed, including demining, soil reclamation, environmental monitoring and the development of strategies for sustainable land use.

Assessment of damage from military operations is an important stage of recovery, as it allows to determine the scale of destruction, set priorities and develop effective mechanisms for reconstruction. The use of modern technologies and international experience will contribute to faster recovery and provide a basis for sustainable development Economic assessment of damages and costs of land restoration is a key aspect of planning restoration measures..

It allows for rational allocation of resources, prevention of further land degradation and attraction of financing for their rehabilitation. This is especially relevant for countries affected by military conflicts, where damage assessment should be an integrated part of state policy. [20]

Loss of productivity and decrease in land value threaten the agricultural sector and sustainable development. To overcome these problems, it is necessary to apply modern assessment methods, innovative approaches to land management and strengthen state support for the agricultural sector.

Reclamation of degraded soils is a necessary measure for preserving ecological balance and sustainable land use. Biological, physicochemical and engineering methods allow for effective restoration of soil fertility and prevention of further deterioration of their condition.

[20] M. Mityaev, I. Novakovska, N. Komarova, L. Smolenska. (2024). Ecological sustainability of urbanized areas: challenges and opportunities for integration into spatial planning. Moderní aspekty vědy: XLIX. Díl mezinárodní kolektivní monografie / Mezinárodní Ekonomický Institut s.r.o.. Česká republika: Mezinárodní Ekonomický Institut s.r.o., str. 527-560. https://doi.org/10.52058/49-2024

Rehabilitation of lands after military operations requires a comprehensive approach, including effective environmental policy, implementation of innovative technologies and attraction of international support. This will contribute to the restoration of the natural potential of territories and ensuring their sustainable use.

For effective ecological rehabilitation of lands in Ukraine, it is necessary to improve institutional and legal mechanisms, intensify state and international support and introduce modern technologies. Only with the coordination of all stakeholders can one achieve high-quality restoration of land resources and ensure their rational use in the future.

SUMMARY

The section is devoted to assessing the impact of military actions on land resources, determining environmental and economic damage, as well as developing mechanisms for their rehabilitation. War leads to soil degradation, chemical and radiation contamination, mine hazard, loss of biodiversity and serious socio-economic consequences.

An analysis of the scale of destruction of Ukraine's land fund was conducted and financial losses in the agricultural sector were estimated, including reduced yields, damage to agricultural machinery, soil contamination and a decrease in the investment attractiveness of regions. The proposed mechanisms for environmental rehabilitation include demining, soil reclamation, biological and engineering restoration methods, as well as the introduction of environmental protection technologies.

The study emphasizes the need to integrate environmental measures into state land use policy, the development of modern damage assessment methods and international support for the effective restoration of Ukraine's land resources.

Bibliography

1. Статистичний щорічник України за 2021 рік. https://www.ukrstat.gov.ua/druk/publicat/kat_u/ 2022 /zb/ 11/ Yearbook_2021.pdf

2. Україна має найвищий відсоток розораності земель в світі. https://agronews.ua/news/ukrayina-maye-najvyshhyj-vidsotok-rozoranostizemel-v-sviti/

3. Звіт про стратегічну екологічну оцінку Державної стратегії регіонального розвитку на 2021 – 2027 роки. 2023. 92 с. URL: https://mtu.gov.ua/files/__Report%20SEA%20SSRD-2027%20v.2%20(4).pdf

4. *С. Балюк, А. Кучер, М.Солоха.* Оцінка впливу війни на чорноземи як передумова відновлення їхньої родючості.2024. URL: https://agroportal.ua/blogs/ocinka-vplivu-viyni-na-chornozemi-yak-peredumova-vidnovlennya-jihnoji-rodyuchosti

5. О. Ангурець, П. Хазан, К. Колесникова, М. Кущ, М. Чернохова, М. Гавранек. Наслідки для довкілля війни росії проти України. 2022. 84

с. URL: https://cleanair.org.ua/wp-content/uploads/2023/03/cleanair.org.ua-war-damages-ua-version-04-low-res.pdf

6. Рачков С.М. Методичні рекомендації «Правила поводження з вибухонебезпечними предметами», 2023. Харків. URL: https://nmc.dsns.gov.ua/upload/3/8/1/4/5/metodicka-pravila-povodzennia-z-vnp.pdf

7. Війна та екологія: чому природа стає жертвою збройного конфлікту? 2023. URL: https://iaa.org.ua/articles/vijna-ta-ekologiya-chomu-pryroda-staye-zhertvoyu-zbrojnogo-konfliktu/

8. Мединська Н.В., Новаковська І.О., Подлєгаєв В.П., Кулініч А.О. Лісова стратегія України: інтеграція екологічних та економічних підходів. Успіхи і досягнення в науці. № 4 (4). 2024. Сс.755– 767. https://doi.org/10.52058/3041-1254-2024-4(4)-755-767

9. Дайджест ключових наслідків російської агресії для українського довкілля за 2-8 червня 2022 року. URL: https://mepr.gov.ua/dajdzhest-klyuchovyh-naslidkiv-rosijskoyi-agresiyi-dlya-ukrayinskogo-dovkillya-za-2-8-chervnya-2022-roku/

10. Звіт про прямі збитки інфраструктури від руйнувань внаслідок військової агресії Росії проти України станом на початок 2024 року. URL: https://kse.ua/wp-content/uploads/2024/04/01.01.24_Damages_Report.pdf

11. Про затвердження Методики визначення військових втрат, завданих Україні внаслідок збройної агресії Російської Федерації: наказ Міністерства оборони України від 14.09.2022 р. № 277. URL: https://zakon.rada.gov.ua/laws/show/z1471-22#Text

12. Про затвердження Методики визначення розміру шкоди завданої землі, ґрунтам внаслідок надзвичайних ситуацій та/або збройної агресії та бойових дій під час дії воєнного стану: наказ Міністерства захисту довкілля та природних ресурсів України від 04.04.2022 р. № 167. URL: https://zakon.rada.gov.ua/laws/show/z0406-22#Text

13. Мединська Н.В., Новаковська І.О., Близнюк В.В. Вплив рентних платежів на природокористування: аналіз економічних й екологічних аспектів сьогодення та в період післявоєнного відновлення. Актуальні питання у сучасній науці № 6(24) 2024. Сс. 118-131. https://doi.org/10.52058/2786-6300-2024-6(24)-118-130

14. В. Ладиченко, Н. Мединська, І. Новаковська, Б. Яринко Правові аспекти захисту земель як національного багатства України в умовах агресії: міжнародні та національні підходи. Національні інтереси України. № 3 (3). 2024. Сс 210-224 https://doi.org/10.52058/3041-1793-2024-3(3)-210-224

15. Р. Нейтер, С. Зоря, О.Муляр. Збитки, втрати та потреби сільського господарства через повномасштабне вторгнення. 2024. 33 с. URL: https://kse.ua/wp-content/uploads/2024/02/RDNA3_ukr.pdf

16. Ткачук В.А., Мединська Н.В., Новаковська І.О., Костюк Т.О. Інтеграція соціальних та економічних факторів для сталого розвитку сільських територій в умовах сучасних викликів. Наукові інновації та

передові технології (Серія «Економіка»), № 11(39), 2024. 330–322 https://doi.org/10.52058/2786-5274-2024-11(39)-733-749

17. Офіційний сайт Державної екологічної інспекції України. URL: https://www.dei.gov.ua/post/2694

18. I. Novakovska, N. Medynska, L. Hunko, L. Skrypnyk, V. Samsonova, N.Shevchenko.(2024) Formation of the economic mechanism of nature management in the conditions of new global environmental architectonics . Opportunities and Risks in AI for Business Development Volume 2. Pp. 313-326. https://doi.org/10.1007/978-3-031-65207-3

19.. Бавровська Н.М., Іщенко Н.Ф., Новаковська І.О. Стан і перспективи досягнення індикаторів цілей сталого розвитку в умовах воєнного стану та повоєнного відновлення. Наука і техніка сьогодні. 2025. № 1 (45). Сс. 204-216. https://doi.org/10.52058/2786-6025-2025-1(42)-204-216

20. M. Mityaev, I. Novakovska, N. Komarova, L. Smolenska. (2024). Ecological sustainability of urbanized areas: challenges and opportunities for integration into spatial planning. Moderní aspekty vědy: XLIX. Díl mezinárodní kolektivní monografie / Mezinárodní Ekonomický Institut s.r.o.. Česká republika: Mezinárodní Ekonomický Institut s.r.o., str. 527-560. https://doi.org/10.52058/49-2024

Information about the authors:
Novakovska Iryna Oleksiivna,
Doctor of Economic Sciences, professor.,
Chlen korespondent NAAS,
Professor of the Department of Land Cadastre
National University of Life and Environmental Sciences of Ukraine
Str. Heroyiv Oborony, 15, Kyiv, 03041, Ukraine

Ishchenko Nataliia Fedorivna,
PhD in Economics, Associate Professor,
Associate Professor of the Department of Aerospace Geodesy and Land Management
State University «Kyiv Aviation Institute»
Lubomyr Husar Avenue, 1, Kyiv, 01001, Ukraine

Skrypnyk Liliia Ruslanivna,
PhD in Economics, Associate Professor,
Associate Professor of the Department of Aerospace Geodesy and Land Management
State University «Kyiv Aviation Institute»
Lubomyr Husar Avenue, 1, Kyiv, 01001, Ukraine