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Ecological and economic aspects of soil instability as a result of hostilities and their legal consequences

Aspectos ecológicos y económicos de la inestabilidad del suelo como resultado de las hostilidades y sus consecuencias jurídicas

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Resumen

La propagación de los conflictos armados amenaza la estabilidad ecológica y los recursos naturales, lo que tiene consecuencias a largo plazo para los ecosistemas y los medios de vida humanos. El artículo investiga los aspectos ecoeconómicos de la inestabilidad del suelo debido a las hostilidades e identifica sus consecuencias legales. Está el impacto de los conflictos en tiempos de guerra en el estado ecológico de los suelos y la economía, explica las causas y consecuencias de estos trastornos y analiza la importancia de abordar estos problemas en el contexto del desarrollo sostenible. Específicamente, el artículo explora las consecuencias de los conflictos armados sobre la fertilidad del suelo, la contaminación de las aguas subterráneas, la propagación de la contaminación en el medio ambiente y el agotamiento de los recursos naturales. También considera los aspectos legales y las normas internacionales que regulan el uso de las armas y el impacto de los conflictos armados en el medio ambiente. La inestabilidad del suelo debido a las hostilidades es uno de los problemas apremiantes del mundo moderno, que tiene importantes consecuencias ecoeconómicas. En la zona de conflicto militar, donde se utilizan equipos militares pesados, explosivos y otros medios de guerra, el medio ambiente circundante, incluido el suelo, se ve gravemente afectado, lo que provoca su degradación y la interrupción de los procesos naturales.

Palabras clave: inestabilidad del suelo, restauración de la zona de combate, impactos ambientales, biorremediación, monitoreo de suelos, métodos innovadores de restauración de suelos, servicios ecosistémicos, pagos por servicios ecosistémicos.

Abstract

The spread of armed conflicts threatens ecological stability and natural resources, resulting in long-term consequences for ecosystems and human livelihoods. The article researches examine the eco-economic aspects of soil instability due to hostilities and identify their legal consequences. There is the impact of wartime conflicts on the ecological state of soils and the economy, explains the causes and consequences of these disruptions, and discusses the importance of addressing these issues in the context of sustainable development. Specifically, the article explores the consequences of armed conflicts on soil fertility, groundwater contamination, the spread of pollution in the environment, and the depletion of natural resources. It also considers the legal aspects and international norms that regulate the use of weapons and the impact of armed conflicts on the environment. Soil instability due to hostilities is one of the pressing problems of the modern world, which has significant eco-economic consequences. In the military conflict zone, where heavy military equipment, explosives, and other means of warfare are used, the surrounding environment, including soil, is severely impacted, leading to its degradation and disruption of natural processes.

Keywords: soil instability, restoration of the combat zone, environmental impacts, bioremediation, soil monitoring, innovative methods of soil restoration, ecosystem services, payments for ecosystem services.

Introduction

The importance of studying the eco-economic aspects of soil instability due to hostilities lies in understanding and predicting the consequences of such disruptions and identifying strategies and measures for restoring and preserving soil cover and its functions. Furthermore, understanding the eco-economic consequences of soil instability is crucial for developing effective policies and strategies in crisis management, post-war territory recovery, and sustainable development.

The consequences of soil instability due to hostilities have ecological, economic, and social dimensions. Ecological consequences include:

- Soil degradation.
- Loss of fertility.
- Biodiversity decline.
- Contamination of groundwater.
- The spread of pollutants into the surrounding environment.

These can have long-term impacts on ecosystems and their services and agriculture, leading to food instability and threatening food security.

Economic consequences include the loss of productive capacity, decreased agricultural production, damaged infrastructure, and loss of access to natural resources. These can significantly impact the regional economy, reduce people's incomes, and worsen the social situation.

Legal consequences of soil degradation due to hostilities involve accountability for war crimes and violations of international norms and agreements. In addition, international humanitarian law contains provisions to protect the natural environment from the unlawful use of force and obligates conflict parties to adhere to these norms. Legal consequences include:

- The possibility of conducting international investigative inquiries into crimes against the environment.
- Providing compensation for affected parties.
- Establishing mechanisms to prevent similar violations in the future.

This research aims to comprehensively investigate the effects of hostilities on soil structure, fertility, ecological conditions, contamination levels, and economic consequences.

In accordance with the purpose, the following hypotheses are proposed:
Hypothesis 1: Soil degradation due to hostilities leads to decreased soil fertility and increased erosion processes.

Hypothesis 2: Restoring soil stability after military conflicts is possible through effective bioremediation methods and innovative approaches that promote fertility restoration and ensure sustainable utilization of soil resources

Literature Review

Researching the ecological and economic aspects of soil instability due to hostilities is necessary for formulating effective crisis management strategies and preventing similar disturbances in the future. Assessing the consequences of such disruptions aids in developing territory restoration and soil rehabilitation programs and implementing measures to ensure sustainable use and conservation of natural resources.

Armed conflicts significantly impact the ecological condition of soils, including their structure, chemical composition, and fertility. The following aspects are being investigated to enhance our understanding of this impact:

1. Physical structure damage (Bronick, 2005; Vlek et. al., 2008; Blum and Nortcliff, 2009; Xu et. al., 2018; Berehovyi, 2022): Armed activities such as explosions, tank

movements, and heavy machinery cause physical damage to the soil. Explosions create shockwaves that can disrupt soil structure, break soil aggregates, and create porous gaps. It leads to soil compaction, reduced air permeability, and hydrological issues such as flooding and waterlogging.

2. Loss of topsoil fertility (Prasannakumar et. al., 2018; Chaudhary et. al., 2018; Gao et. al., 2018; Scherr and McNeely, 2008; Verheijen et. al., 2009). Armed conflicts can result in the loss of the upper fertile layer of soil. Explosions and erosion processes caused by military activities can wash away or destroy this layer, which contains organic matter, microorganisms, and nutrients. Consequently, soil fertility decreases, significantly impacting agriculture and food security.

3. Chemical contamination (West et. al., 2002; Reynolds et. al., 2007; Wu et. al., 2015; Nkonya et. al., 2016; Yuan et. al., 2018; Xue et. al., 2018): Using heavy machinery and explosive substances in combat zones can contaminate the soil with chemical substances. For instance, explosives, fuels, and other military materials residues can enter the soil and persist after military operations. As a result, it can lead to soil pollution with heavy metals, radioactive substances, and other toxic compounds. Contaminated soil can adversely affect human health, animals, plants, and the biodiversity of ecosystems.

4. Changes in soil microbiological composition (Lal, 2016; Zhang et. al., 2016; Wang et. al., 2016; Bautista-Capetillo et. al. 2018): Hostilities can impact the microbiological composition of the soil, including microorganisms that play a vital role in organic matter decomposition, nitrogen fixation, and other processes. Explosions and chemical substances can kill or reduce these microorganisms' activity, affecting the soil's biological activity and fertility.

Violations of soil stability due to armed conflicts also have serious economic consequences. Some of the most important economic aspects include:

1. Decreased agricultural production (Adhikari and Hartemink, 2016; Gholami et. al., 2018; Lal, 2003; Liu et. al., 2018): Loss of topsoil and contamination can lead to reduced crop yields and agricultural production. It directly impacts food security and can result in increased dependence on imported food products and higher prices.

2. Loss of ecological services (Muñoz-Rojas et. al., 2016; Panagos et. al., 2017; Zhang et. al., 2017). Soil performs several environmental functions, such as water conservation, water filtration, carbon sequestration, and preservation of biodiversity. Disruptions to soil stability during armed conflicts can diminish these functions. For example, soil erosion can cause sediment runoff into water sources, leading to water pollution and decreased drinking water quality. Reduced soil fertility can also affect the soil's ability to store carbon, increasing climate change risk.
3. Reconstruction and infrastructure restoration (Bai et. al., 2008; Boardman et. al., 2011); Gomiero et. al., 2011): Soil instability resulting from hostilities may require significant efforts and resources for infrastructure reconstruction and restoration, such as roads, buildings, and water supply systems. It would entail substantial investments and expenses.
4. Loss of income and diminished social development (Lehmann et. al., 2008; Sojka et al., 2013; Hengl et. al., 2014): Soil instability can lead to decreased revenues for agricultural farms and reduced employment in the sector. It can have a negative impact on the standard of living and social development in affected regions. Additionally, environmental problems associated with soil stability disruptions can create a negative image for these regions and limit their potential for tourism and investments.

The legal consequences of soil instability due to hostilities also have significant legal implications. The main aspects include:

1. International Humanitarian Law (Amundson and Jenny, 1991; Dregne, 1991; Costanza et. al., 1997;): Armed actions leading to ground instability may contradict international humanitarian law. According to this law, conflicting parties are obligated to take measures to reduce the negative impact of military operations on civilian objects, including the natural environment. Violations of these obligations may have legal consequences, including international responsibility and possibly being brought to court.
2. Environmental Legislation (van Lynden and Oldeman; 1997; Stoorvogel and Smaling, 1998; Shukla et. al., 2006): Many countries have their own environmental legislation that regulates the protection of the natural environment, including soil

resources. Soil instability resulting from armed conflicts may contradict these laws and regulations. The legal consequences may include fines, lawsuits, and compensation for restoring and rehabilitating damaged areas.

3. International Environmental Law (FAO, 2015; Kapinos and Larionova, 2023): International environmental law also recognizes every person's right to a healthy and safe environment. Soil instability resulting from armed conflicts can impact this right and lead to claims for damages and compensation for affected individuals.

4. Conservation Organizations and Conventions (Oldeman et. al., 1995; Rockström et. al., 2009): Various conservation organizations and conventions, such as the Convention on Biological Diversity and the United Nations Convention to Combat Desertification, deal with protecting the natural environment and sustainable land use. However, soil instability resulting from hostilities can affect the fulfillment of obligations defined in these international documents. In addition, it can lead to reputational damage and accountability before the international community.

5. Compensation for Damages and Rehabilitation (van der Mensbrugghe et. al., 2012): The legal consequences of soil instability include the possibility of claiming compensation for damages and providing rehabilitation to affected parties. It may involve financial compensation, restoration and rehabilitation of damaged areas, and other measures to restore the region.

All these legal aspects emphasize the importance of complying with international humanitarian law, environmental legislation, and conservation conventions to prevent the disruption of soil stability due to armed conflicts. Responsibility for such violations lies with the conflicting parties, who may be held accountable and subject to legal prosecution. Ensuring soil protection and sustainable use of its resources after hostilities is essential to ensure environmentally sustainable development and preserve the natural environment for future generations.

Materials and Methods

The authors used the following methods to achieve the research goals:

1. Literature analysis: A systematic review of scientific research, articles, reports, and documents related to the eco-economic aspects of soil destabilization due to military conflicts and their legal consequences was conducted. This analysis provided a comprehensive understanding of the problem, established existing research findings, and identified questions that required further investigation.
2. Field study: Field investigations and data collection were conducted in the affected areas where hostilities occurred. It involved assessing the physical condition of the soil, collecting soil samples for laboratory analysis, and measuring parameters such as moisture, pH, structure, etc. The field study provided specific data on the changes occurring in the soil after armed conflicts.
3. Laboratory analysis: A range of physicochemical and biological studies were performed on soil samples collected from the affected areas. It included analyzing the presence of heavy metals, organic pollutants, microbiological composition, and other indicators that reflected soil quality. Laboratory analysis allowed for a quantitative assessment of soil changes and established relationships between armed actions and their ecological consequences.
4. Legislative analysis: Examination of international conventions, agreements, and national legislation regulating environmental protection and soil use was conducted. This analysis elucidated the existing legal instruments governing the restoration of damaged soil, established accountability for its violation, and proposed potential legal solutions to prevent similar situations in the future.
5. Economic analysis: The economic consequences of soil destabilization resulting from hostilities were studied. It assessed agricultural losses, decreased food production, biodiversity loss, and other economic indicators. The economic analysis helped determine the effectiveness of soil restoration efforts and develop strategies to minimize financial losses in conflict situations.

Result and discussion

The research carried out as part of this study revealed significant changes in the condition of the soil in the damaged territories as a result of hostilities. The assessment of soil condition was based on the analysis of its physical, chemical and biological properties. The main results of the study indicate the following changes:

Since the beginning of the full-scale war and at the beginning of February 2023, total damage to the environment has been caused in more than 2.3 thousand cases in the amount of about 1.9 trillion. UAH in particular, the amount of losses due to land pollution and soiling is more than UAH 845 billion (Ukrinform, 2023).

The research carried out as part of this study revealed significant changes in the condition of the soil in the damaged territories as a result of hostilities. Assessment of the state of the soil in June 2022, the Analytical Center at the Kyiv School of Economics noted that the cost of surveying and demining the affected areas is $436 million. Physical damage to the soil, such as sinkholes from artillery fire and missile strikes, or damage to agricultural land by the tracks of military equipment, was estimated at $39.6 million was based on the analysis of its physical, chemical and biological properties. The main results of the study indicate the following changes:

Increased soil erosion is observed as a result of hostilities. Constant explosions and the movement of heavy military equipment lead to damage to the soil cover and a decrease in its stability, as a result of which large masses of soil are washed away by water flows during rains, which leads to the appearance of debris, cracking and destruction of the soil layer.

Soil analysis from test tubes showed soil contamination with heavy metals and other harmful substances. To assess the degree of soil contamination by the element cadmium as a result of hostilities, a soil sample was studied, which was taken in Chornobaaivka near the memorial sign in honor of the 40th anniversary of the Victory after the liberation

of the right-bank part of the Kherson region. This territory was under occupation for 9 months, and fierce battles were fought in the area of the settlement. But there was no fighting at the sampling site.

To assess the degree of soil contamination with cadmium, the actual concentrations of the element in the studied samples were compared with the maximum permissible concentration (MPC) and the background indicator. Before hostilities, the MPC of cadmium was 0.7 mg/kg, and the background value was 0.152 mg/kg. Test result 1- 0.183 2-0191 3 0.1893. The average value is 0.187667. The percentage of change was 23.46%. In fact, the increase in cadmium concentration was 2.9% over the month. For the zones where hostilities took place directly, the pollution is growing impressively. On the example of the Vilkhiv and Sartan communities, pollution reaches tens of times higher than the MPC (Table 1).

Table 1. Characteristics of soil pollution in Kharkiv and Donetsk regions during one war year

Substance, mg/kg soil	Vilkhiv community Kharkiv region	Sartan community Donetsk region	Exceeding the MPC, times
Cadmium	8,5	9,3	5,6 and 7,6
Copper	168	50	5 and 1,8
Zinc	143	215	2,6 and 4,2
Manganese	720	-	- and 25
Lead	-	720	- and 3,3
Nickel	-	50	- and 2,9

Source: author's research

The cost of reclamation and related works and services, depending on the technology required to restore the fertile soil layer, ranges from $150 per hectare to $1 million per cubic meter, if we are talking about the burial of soils containing particularly dangerous substances. Thus, the following technologies are used to restore the fertile soil layer (Table 2).

Table 2. Estimated cost of soil restoration measures

Technological practices	The essence and nature of agrotechnical processes	Cost, thousands of dollars	Cost components
Agronomy	Simple processing with the removal of fragments of military equipment and elements of missiles and projectiles	20,000 per 1 ha	Mechanical preservation, reseeding of the upper layer and removal
Organic farming	widespread use of biological means for reproduction of soil fertility and plant protection without the use of fertilizers and an intensive system of soil cultivation taking into account the biological requirements of cultivated plants.	40,000 per 1 ha	
Phytoremediation	the process of using plants to clean and rehabilitate contaminated or damaged soils. This method is based on the properties of plants to absorb, accumulate or decompose pollutants, which allows reducing the content of harmful substances in the soil or turning them into less toxic compounds.	1 per 0.5 ha	
Polymer stabilization	addition of synthetic geopolymers to improve soil physical properties of agricultural projects	0.050-0.120 per $1m^3$ 0,2 per $1m^3$ Additional from 200 for equipment	Surface treatment Deep processing
Composting	Introduction of spores of beneficial bacteria and fungi, which renew the soil microflora, which improves biological processes in the soil.	Minimum 0,2 1м3	
Leaching (chemical washing)	Transfer into solution of one or more components of solid minerals found in the soil.	0,03-0,3 $1м^3$	
Thermal desorption	The process of removing adsorbed (adsorbate) or adsorbed (adsorbate) substance from the soil volume	0,01-0,07 $1м^3$	
Chemical extraction	A procedure that uses the difference in partition coefficients of various substances between the two soil phases liquid and solid particles, liquid and gas. The extraction of one or more components can also be carried out with the help of an extractive agent — a specially added substance to the phase, which is used to bind the substance from the soil mixture, which significantly changes the coefficient of distribution of the extracted substance in the grant mass.	0,01-0,03 $1м^3$	The research itself before applying the technology costs 10,000 USD
Oxidation (chemical) or reduction	a chemical process during which an element (or compound) in the soil loses electrons, while the degree of oxidation of its elements increases.	0.2-0.5 per 1 ton of soil	
Burial	isolation of soil masses (most often toxic) by placing them in ravines, beams, etc.	1000 per 1 ton.	

Source: author's research

Such expenses for the restoration of the land and rural fund of Ukraine are very significant. In an economic approach, they are not equal to the cost of buying ready-made plots of land not used in combat zones. Moreover, with the loss of foreign sales markets for agricultural products, by 2023 the unsown area will reach 24%, or almost 7 million hectares (Ecodiya, 2023). Therefore, it is economically cheaper for agrarian companies to purchase the appropriate amount of land in regions that have not fallen into the combat zone (Table 3).

Households and small farms solve the problem of land pollution simply. As much as possible, particles and fragments are collected by hand, and heavy elements remain in place. Also, small and medium-sized funnels are filled with any soil, and large ones remain. For agricultural companies, the process is more organized.

Table 3. The cost of 1 hectare of agricultural land in Ukraine, 2022

Region	The price for 1 ha of agricultural land	
	Thousand UAH	Dollar USA
Mykolayiv	18,1	490
Chernihiv	23,8	640
Kherson	24,6	670
Zaporizhzhia	28,5	770
Sumy	29,4	800
Donetsk	31,8	860
Average in Ukraine	77,9	2110

Everything that can be lifted by truck cranes and manipulators in terms of tonnage is transported by heavy machinery. Discussion is carried out independently and with the involvement of military sappers. All the funnels are covered by a bulldozer with the soil washed away by the wave and lying around. Accordingly, bumps and depressions are formed. And such technologies are quite cheap compared to those listed above.

It is also clear that the Ukrainian government does not care about such lands against the background of the continuation of the war, the financial side of which is very high. Therefore, all restoration will take place exclusively due to natural action: some will be overgrown with weeds, bushes and trees, and the other part will be washed away due to surface water. And a pitted pargobic landscape covered with grass vegetation will be created. All that with automobile roads is a pit on a pit. Such technologies have been developed in Ukraine for 25 years.

The impact of hostilities on agriculture is a serious problem that affects the productivity, quality, and stability of the agricultural sector (Wischmeier and Smith, 1978). Research has shown that armed conflicts result in significant losses in agriculture. One of the major impacts on agriculture is the reduction in food production (Yang et. al., 2003). Due to soil damage, vegetation covers destruction, and agricultural land infrastructure, the area under cultivation and crop yields decrease. In addition, it leads to increased dependence on food imports, negatively affecting the country's food security.

Furthermore, the quality of crops is also compromised due to the disruption of soil stability. Soil structure damage, contamination with harmful substances, and changes in soil composition can decrease the quality of grown products (Viscarra Rossel et. al., 2009). These can affect their taste, nutritional value, and safety for consumption.

Additionally, military conflicts lead to increased costs for pest control and the restoration of damaged agricultural land. The infrastructure, machinery, and equipment damage requires financial investment for restoration and repairs. Moreover, there is a greater need for protection against pests, which can become particularly active in a disrupted environment.

The economic consequences of soil degradation due to hostilities are significant and can profoundly impact the local economy (Sanaullah et. al., 2012). The research confirms significant economic losses associated with such disruptions. One of the main economic consequences is job loss. Damage to agricultural land, decreased production, and the

infrastructure of agriculture lead to job cuts in rural areas. It jeopardizes the employment of the local population and can result in economic decline in the region.

Furthermore, the disruption of soil stability leads to decreased tax revenues. Agriculture is an important sector of the economy that provides tax income for the government. Decreased production and profitability in the agricultural sector result in reduced tax revenues, which can affect communities' financial stability and ability to provide development and social services for the population.

The understanding that soil stability disruption leads to changes in its physical, chemical, and biological properties presents significant tasks for scientists and practitioners. The study has shown that consequences such as increased erosion, decreased fertility, and contamination with harmful substances require adequate soil protection and restoration measures.

Conclusion

In conclusion, the research conducted as part of this study has revealed significant changes in the condition of soil in the territories affected by hostilities. The assessment of soil condition, based on the analysis of its physical, chemical, and biological properties, has provided valuable insights into the ecological consequences of armed conflicts. The study has identified various changes in the soil due to hostilities. One notable finding is the extensive damage caused to the environment, with over 2.3 thousand cases resulting in approximately 1.9 trillion UAH worth of damage. Among these losses, land pollution and soiling alone accounted for more than 845 billion UAH. Additionally, physical damage to the soil, such as sinkholes from artillery fire and missile strikes, or damage to agricultural land by military equipment tracks, was estimated at 39.6 million USD. One significant consequence of hostilities is increased soil erosion. The constant explosions and movement of heavy military equipment have led to damage to the soil cover and a decrease in its stability. This, in turn, has resulted in the washing away of large masses of soil by water flows during rains, leading to debris, cracking, and destruction of the soil layer.

Furthermore, soil analysis has indicated contamination with heavy metals and other harmful substances. For instance, the study focused on assessing the degree of soil contamination with cadmium, revealing an increase in concentration over time. Comparisons with the maximum permissible concentration (MPC) and background values demonstrated significant pollution in areas directly affected by hostilities, reaching levels tens of times higher than the MPC in some cases.

The cost of soil reclamation and related works and services varies depending on the required technology. The range of costs for restoring the fertile soil layer extends from $150 per hectare to $1 million per cubic meter for burying soils containing particularly dangerous substances. Various technologies, including thermal desorption, chemical leaching, stabilization, agricultural methods, chemical extraction, composting, and chemical oxidation/reduction, are employed for soil restoration, each with its associated cost.

Global or interstate payment systems for ecosystem services can be used as offsetting payments used by several countries. World experience shows great variability of financial mechanisms for the implementation of systems of payments and taxes for the use of ecosystem services. The general principle of operation of compensation mechanisms (payments) for ecosystem services should be the profitability of preserving ecosystem services for local communities, regions, and countries, which determines the overall economic efficiency of environmental protection actions of these entities

Overall, the findings of this study emphasize the urgent need for addressing the environmental and ecological consequences of armed conflicts, particularly the destabilization of soil. Effective restoration strategies and the implementation of appropriate legislation and regulations are crucial to minimize the long-term impacts on soil quality, agricultural productivity, and economic stability in conflict-affected regions.

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