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# Spatial-Temporal Analysis of Forest Cover Changes in Zaporizhzhia Oblast Due to Military Factors

***M. Hanchuk*** *(Dmytro Motornyi Tavria State Agrotechnological University)*, ***L. Datsenko*** *(Dmytro Motornyi Tavria State Agrotechnological University)*

## *SUMMARY*

This study presents a spatial-temporal analysis of changes in forest cover and forest shelter belts in Zaporizhzhia Oblast under the influence of military factors using Earth remote sensing (ERS) data and geographic information systems (GIS). The relevance of the research is determined by the increasing scale of forest ecosystem degradation resulting from combat operations, fires, explosive damage, soil cover disturbance, and changes in the natural resource use regime.

The information base consisted of satellite images of medium and high spatial resolution, which enabled determination of forest area dynamics, localization of damage centers, and assessment of transformation intensity during different periods of military impact. Methods of multi-temporal analysis, index-based vegetation condition assessment (NDVI and derivatives), spatial modeling, and change mapping were applied.

As a result, the main trends in reduction and fragmentation of forest areas were established, territories with the highest level of anthropogenic-military load were identified, and potential zones of further degradation risk were delineated. The obtained results can be used for developing forest ecosystem restoration measures, improving environmental monitoring systems, and making management decisions in the field of regional environmental security.

## Introduction

Forest ecosystems are an important component of the natural environment, performing soil protection, water conservation, climate regulation, and biodiversity functions. For the steppe regions of Ukraine, particularly Zaporizhzhia Oblast, forest-covered areas have special significance as an element of landscape ecological stability, wind erosion reduction, microclimate formation, and agricultural landscape productivity maintenance. At the same time, their share in the regional land use structure is relatively small, which increases the vulnerability of forest areas to anthropogenic and natural factors.
Full-scale military operations have caused significant transformations of natural territories, particularly forest plantations. Fires, mechanical damage, mining, infrastructure destruction, and restricted access to forestry activities have led to changes in the structure, area, and spatial configuration of forest-covered territories. Under such conditions, the need for rapid and objective assessment of the scale and dynamics of these changes becomes particularly relevant.
An effective research tool is the use of Earth remote sensing (ERS) data in combination with geographic information systems (GIS), which provide the capability for multi-temporal analysis, mapping, and quantitative assessment of forest cover transformations. The spatial-temporal approach enables identification of change patterns, determination of the centers of greatest military impact, and formation of an information basis for subsequent restoration and ecological management of the territory.
Modern satellite forest fire monitoring systems enable (Chetverikov & Kalynych, 2022; Osadchyi et al., 2023): monitoring of the forest fire situation; assessment and provision of information on forest fire parameters; detection of smoke zones and areas from forest fires; detection of forest fires at different stages of their development.
The FIRMS (Fire Information for Resource Management System) service was developed at the University of Maryland and is supported by the National Aeronautics and Space Administration (NASA). The system uses publicly available satellite imagery.

## Method and Theory

The research materials consisted of open data from the State Environmental Inspection, the State Emergency Service, the Fire Information for Resource Management System (FIRMS), Global Forest Change (GFC), as well as freely available satellite images (Sentinel-2, Landsat 8/9). The research was conducted during 2023-2025.
Research methods: geoinformation methods (GIS analysis) – applied for spatial data processing and mapping of damaged areas; Earth remote sensing methods – used for detecting forest area transformations, analyzing vegetation indices (NDVI), and identifying degraded and disturbed areas in dynamics; statistical and comparative methods – applied for analyzing obtained results and establishing patterns of indicator changes.
The following methodologies were used in the study: analysis of forest cover losses using ERS methods (Hansen et al., 2013); analysis of forest fires based on ERS data (SRNA Syamala et al., 2021).

## Results

Based on FIRMS MODIS product data (Terra, Aqua) (Giglio et al., 2016), a map scheme of fire distribution across Zaporizhzhia Oblast was compiled. Analysis of the map scheme enables determination of spatial and temporal patterns of fire distribution. Under combat conditions, the application of satellite monitoring tools can be considered virtually the only alternative method for obtaining relatively reliable data.
To demonstrate an example of thermal anomaly (fire) distribution analysis, we selected the following time frame – September 1-30, 2025 (Fig. 1). The spatial distribution of fires can be clearly classified into two categories. The first is associated with the line of contact with the enemy, while the second is

located in the interior of Ukrainian territory. When increasing the scale, we can observe specific fire locations. This is where the main limitation of FIRMS becomes evident, related to the low spatial resolution of the source images.

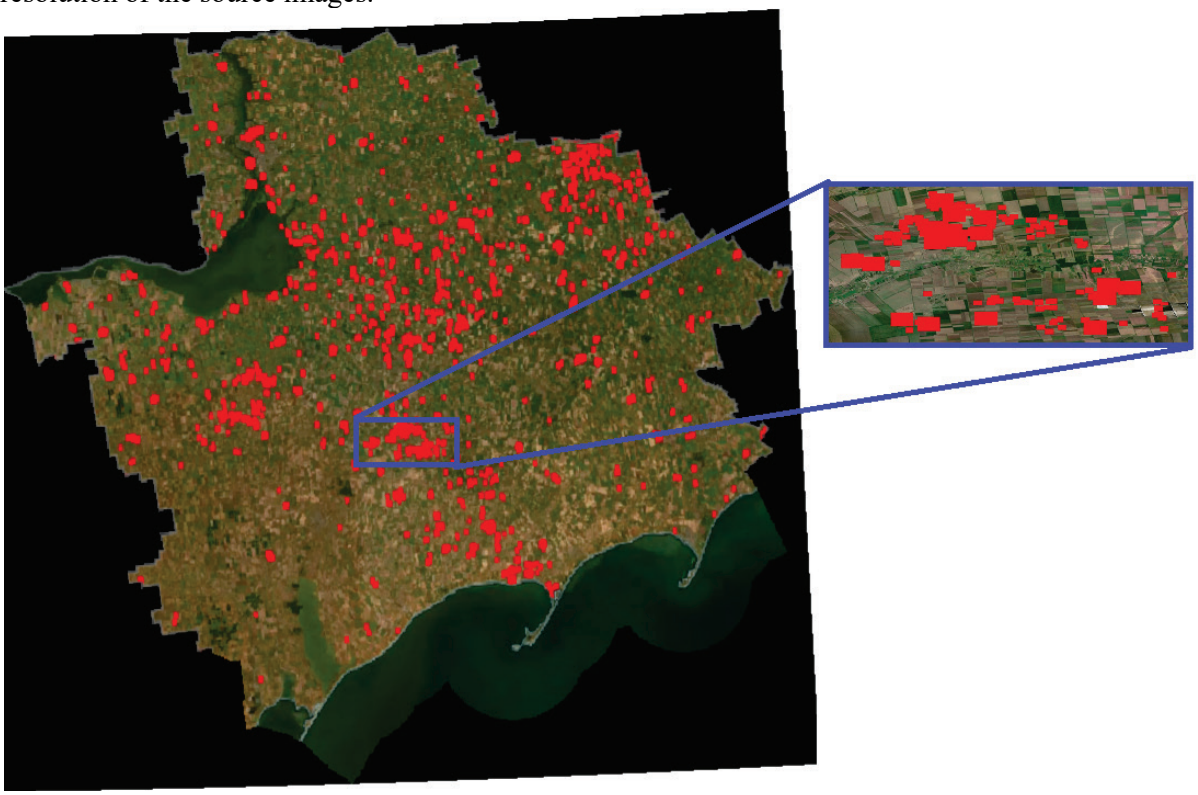

***Figure 1*** *Fire distribution within Zaporizhzhia Oblast according to FIRMS service data (September 2025).*

The next system providing data on the reduction of forest plantation areas is Global Forest Change (GFC). This is a development of the Department of Geographical Sciences at the University of Maryland, which presents results of Landsat time-series image analysis characterizing forest area and changes (Hansen et al., 2013; Skyba et al., 2024).

The data obtained from the Global Forest Change system provide an understanding of the spatial distribution of forest plantations (Fig. 2 A) and forest plantation area losses (Fig. 2 B). This system also has similar problems to the previous one: low spatial resolution of source images.

As of the period before the full-scale aggression, the share of forest-covered territories within Zaporizhzhia Oblast remained critically low – approximately 11 thousand hectares, representing only 0.42% of the region's total area. This indicator reflects the general specificity of Ukraine's steppe zone, where forest ecosystems are fragmented in nature and perform primarily protective and eco-stabilizing functions.

According to analytical materials from the Global Forest Change platform (Hansen et al., 2013), after 2022 the dynamics of changes acquired a sharply negative character. In 2024 alone, natural forest losses reached 430 hectares. According to carbon balance estimates, this is equivalent to the release of approximately 81 thousand tons of $CO_2$ into the atmosphere, which enhances the regional contribution to climate change and reduces the potential for natural greenhouse gas absorption. Cumulatively, since 2022, the total loss area has reached 621 hectares (Fig. 3), indicating the systemic and prolonged nature of degradation processes.

Analysis of forest cover transformation causes demonstrates that large-scale fires became the dominant factor, with an area of approximately 550 hectares. Their occurrence is associated both with direct consequences of combat operations (shelling, ammunition detonation, dry vegetation ignition) and with complicated access to prompt firefighting and implementation of preventive forestry

measures. Besides direct tree stand destruction, fires caused secondary ecological effects: soil cover degradation, water regime disturbance, biotope fragmentation, and biodiversity reduction.

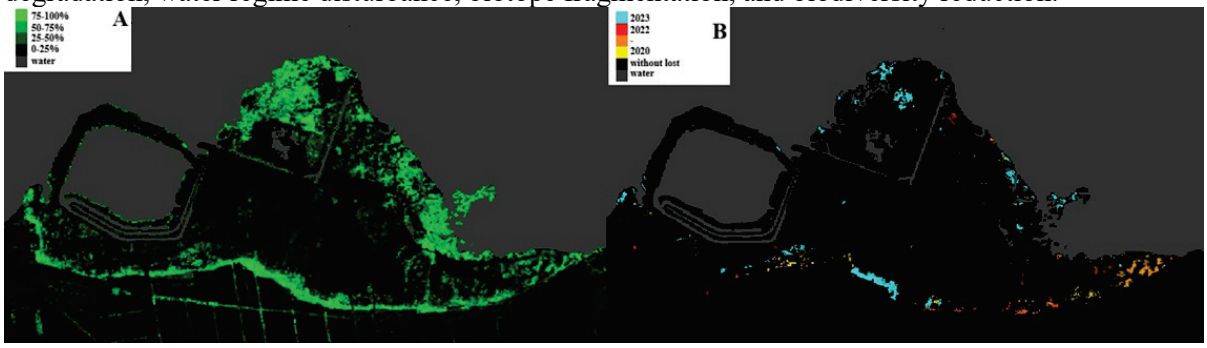


***Figure 2*** *Analysis of forest cover losses using Global Forest Change A – forest-covered areas; B – forest plantation losses.*

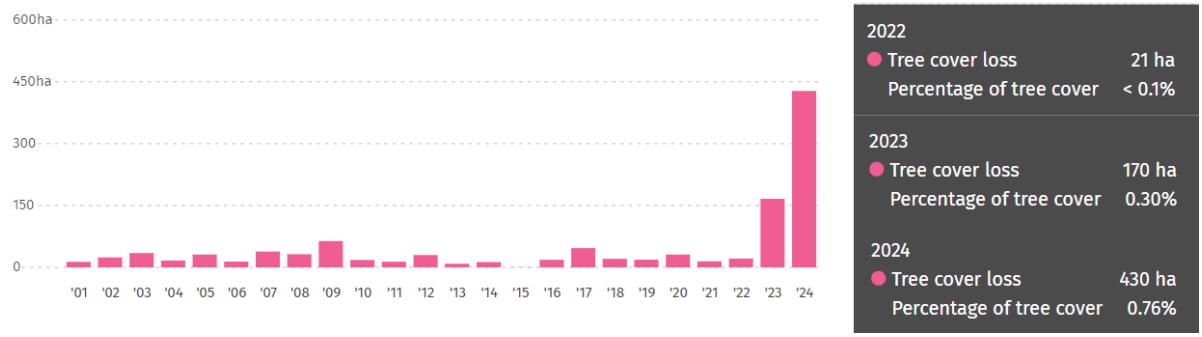


***Figure 3*** *Dynamics of forest cover losses in Zaporizhzhia Oblast during 2001-2024 according to Global Forest Change data.*

During the period from February 24, 2022 to December 15, 2025, 1992 thermal anomalies were recorded within Zaporizhzhia Oblast according to satellite monitoring data (Fig. 4), identified by the VIIRS (Visible Infrared Imaging Radiometer Suite) sensor. These detections represent centers of elevated thermal radiation, which in most cases correspond to active fires or zones of intensive smoldering.

Thus, the recorded losses represent not only a quantitative reduction in forest-covered areas, but also an indicator of deep structural-functional changes in the region's natural complexes, requiring further monitoring based on remote sensing data and spatial analysis in a GIS environment.

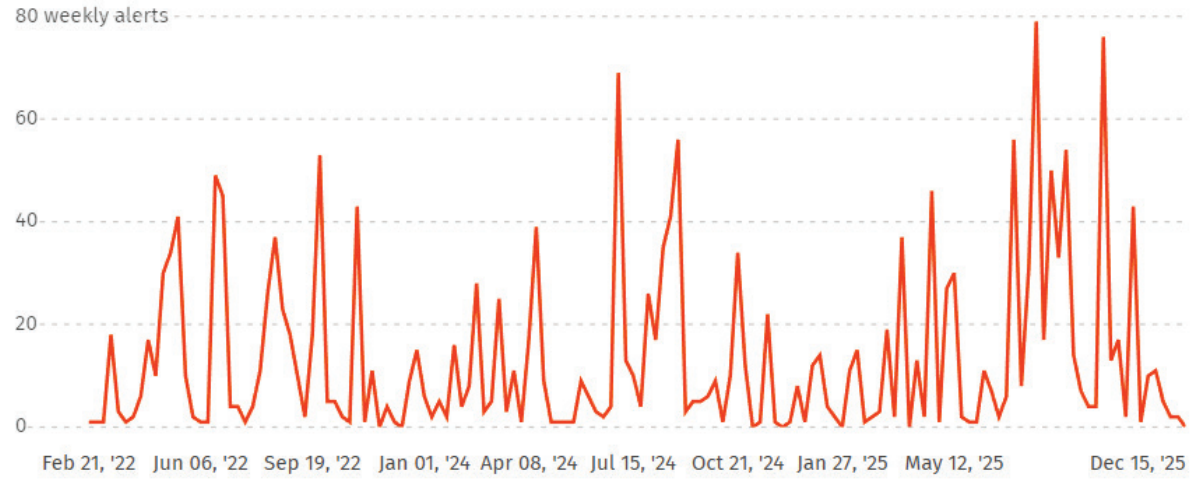


***Figure 4*** *Registration of fire occurrence cases during the period from February 24, 2022 to December 15, 2025 according to VIIRS data.*

According to the State Environmental Inspection data (https://www.pivden.dei.gov.ua/), the area of burned forests and other plantations in the territory of Zaporizhzhia Oblast (controlled territory) amounts to 287.7 hectares, which caused damage of 546,960.40137 thousand UAH.

**Conclusions**

The conducted spatial-temporal analysis confirmed significant deterioration of forest ecosystem conditions in Zaporizhzhia Oblast as a result of military factors during the period 2022–2025. The recorded reduction in forest-covered areas has a systemic character and is accompanied by their fragmentation and decrease in ecological stability.

Before the full-scale aggression, the region's forest cover remained critically low (approximately 0.42% of the territory), which determines increased vulnerability of forest and shelter belt plantations to fires and mechanical damage. The loss of 621 hectares of forests during 2022–2025 is substantial for a steppe region with limited forest resource potential.

Fires became the dominant degradation factor, as confirmed by both Global Forest Change data and the registration of 1992 thermal anomalies. The spatial distribution of fires indicates their concentration both in the combat zone and in rear areas, pointing to the complex nature of military operations' impact.

The assessment of carbon losses (81 thousand tons of $CO_2$ in 2024 alone) demonstrates not only local ecological consequences, but also a negative contribution to the regional greenhouse gas balance. Fires caused secondary effects: soil degradation, hydrological regime disturbance, biodiversity loss, and intensification of erosion processes.

The use of ERS data (Sentinel-2, Landsat 8/9, MODIS, VIIRS) in combination with GIS analysis proved its effectiveness as a tool for operational monitoring under conditions of limited access to territories. At the same time, limitations were identified related to the spatial resolution of FIRMS and GFC satellite products.

The obtained results form a scientifically substantiated basis for planning post-war forest ecosystem restoration measures, improving environmental monitoring systems, and making management decisions in the field of natural resource use and environmental security of Zaporizhzhia Oblast.

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