Remote Sensing and GIS-Based Mapping of War-Induced Fires: Evidence from Sumy Region, Ukraine

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SUMMARY

Military conflicts cause severe environmental degradation, yet active hostilities prevent conventional ground-based monitoring. This study addresses the need for remote, verifiable assessment of war-induced fire damage in Sumy Region, Ukraine - a frontline territory sharing over 560 km of border with Russia, systematically exposed to artillery and aerial bombardment since February 2022. The methodology integrates three cloud-based analytical stages implemented in Google Earth Engine. First, thermal anomalies from NASA fire detection data were filtered spatially and temporally to map fire distribution and density across four contrasting territorial communities. Second, burned area masks were overlaid on a land cover dataset to quantify fire damage by vegetation and land use type. Third, bitemporal vegetation index composites from satellite imagery for 2021 and 2025 were compared to assess ecosystem health transformation. Results show that 28% of Sumy Region (672,683 ha) suffered direct pyrogenic and explosive impact. The most severely affected territorial community lost 73% of its territory, including over 23,000 ha of coniferous forest. Agricultural territorial communities sustained losses exceeding 32,000 ha of cropland. Vegetation index analysis revealed a paradox: secondary succession on mine-contaminated abandoned fields generates artificially elevated readings, masking the true loss of productive agricultural land. The integrated remote sensing approach provides a reproducible framework for environmental monitoring in conflict zones, supporting damage documentation, loss quantification, and evidence-based restoration planning.

Keywords: War-induced environmental damage; War-induced fires; Pyrogenic impact; Remote sensing; GIS; Burned area mapping; Vegetation loss; Sumy Region; Google Earth Engine.

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Introduction

Military conflicts are one of the most destructive human-induced factors contributing to environmental degradation. The full-scale invasion by the russian federation, which began on February 24, 2022, has caused widespread forest and wildfires in Ukraine's border regions. The Sumy region, which borders the russian federation along a stretch of over 560 km, is subjected to systematic artillery and air strikes, resulting in fires of unprecedented scale. The critical nature of the situation is exacerbated by the fact that traditional ground-based monitoring is impossible due to active hostilities, mine contamination, and the constant threat to researchers. Under these conditions, Earth remote sensing (ERS) methods and cloud computing become the only reliable tools for monitoring the state of environmental components and mapping burned areas and vegetation loss (Sakal et al., 2026).

Most scientific publications cover specific aspects of war-related fire impacts on ecosystems: Waśniewski et al. (2026) assessed forest damage using Sentinel-2 imagery; Kussul et al. (2025) and others applied machine learning to analyze changes in land use; Tomchenko et al. (2023) conducted an assessment of fires at the landscape level; Yailymov et al. (2023) investigated automated satellite monitoring of forest fires. However, a comprehensive analysis of the spatiotemporal distribution of pyrogenic impacts on forest and agricultural landscapes at the regional level remains understudied. This is also true for the Sumy region, where the specific nature of the border zone with the aggressor and the intensity of hostilities necessitate detailed studies that will serve as an evidence base for future policies and measures for protection and restoration, which explains the relevance and timeliness of our work.

Method and Theory

For our study, we selected four territorial communities in the Sumy region that demonstrate contrasting conflict scenarios: Trostyanets - which was occupied; Seredyna-Budska - the most forested area; and Bilopillyalya and Velyka Pysarivka - which are predominantly agricultural landscapes. Additionally, an analysis was conducted of the entire Sumy Region (2.34 million hectares) as a regional aggregate.

The methodology was implemented on the Google Earth Engine cloud platform using Python in the Google Colab environment in the following three stages:

1. Geospatial distribution and intensity of thermal anomalies in border communities of Sumy Region. NASA FIRMS data (VIIRS/Suomi NPP with a resolution of 375 m and MODIS Terra/Aqua 1 km) were filtered spatially (borders of Sumy Region, FAO GAUL dataset) and temporally (February 24, 2022 - June 10, 2026) (Fig. 1). To minimize false positives and filter out background noise, an amplitude threshold was applied to the brightness temperature channel (T_{21} > 300 K). The fire density map (Fig. 2) was constructed using the kernel density estimation (KDE) method with a Gaussian kernel (radius 3 km) according to the classical Silverman formula (Silverman, 1986).

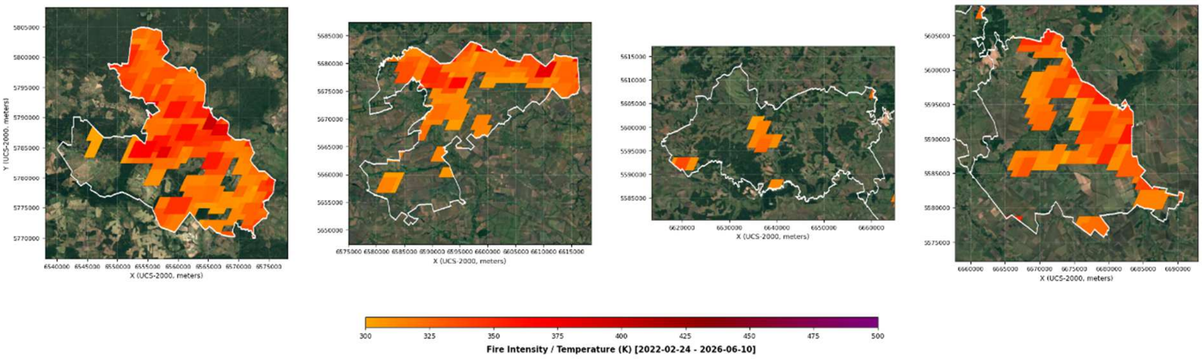
2. Structure of fire damage by land use type. Masks of burned areas obtained from FIRMS thermal anomalies (exceeding the 300 K threshold) were overlaid on the ESA WorldCover 2021 map (10 m) (ESA, 2021) to calculate the areas of damage by category: forests, cropland, and built-up areas (Fig. 3) (ESA, 2021).

3. Assessment of changes in ecosystem vegetation health and burn scars based on spectral indices. Median composite Sentinel-2 Level-2A images (cloud cover < 20%) were generated for the growing season (June-August) of 2021 (pre-war baseline) and 2025 (spatial resolution 10 m). The Normalized Difference Vegetation Index (NDVI) and the Normalized Burn Ratio (NBR) were calculated. Bitemporal differentiation (dNDVI and dNBR) enabled the identification of areas of vegetation degradation, precise delineation of burn scars, and tracking of secondary succession.

AI-assisted tools (Claude, Anthropic) were used for translation support and language editing. All scientific content, analysis, and conclusions are solely the authors' responsibility.

Results

An analysis of NASA FIRMS data from February 24, 2022, to June 10, 2026, was conducted, and a map showing wildfires was created (Fig. 1). On the map, the darker the color, the more intense the fire or explosion.



a) b) c) d)

Figure 1. *Map of fires caused by hostilities in the territory of a) the Seredyna-Buda Territorial Community; b) the Bilopillya Territorial Community; c) the Trostyanets Territorial Community; d) the Velyka Pysarivka Territorial Community*

The KDE density map reveals a pronounced asymmetry in the spatial distribution of thermal anomalies (Fig. 2). Here, the spatial distribution of fire epicenters exhibits a distinct asymmetry and specific geometry. The vast majority of thermal anomalies of the highest intensity (areas marked in red and orange) form a continuous band that clearly follows the contours of the state border with the russian federation. Such an abnormally high density of hotspots specifically in the border buffer zone is direct confirmation of their military origin.

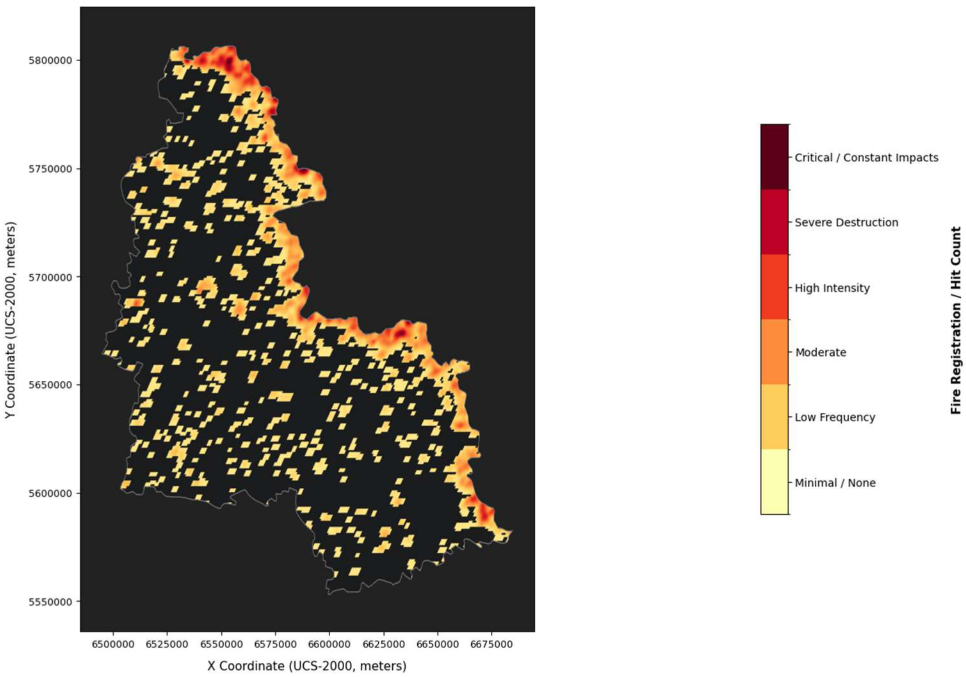
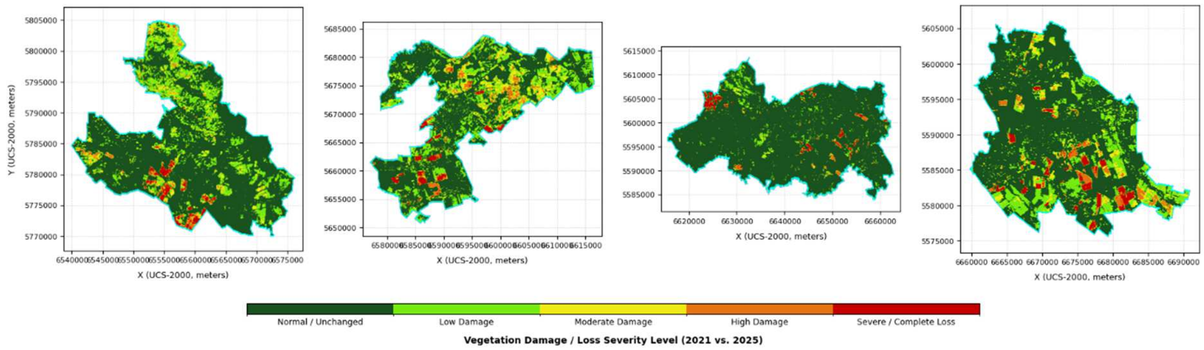


Figure 2. *Heat map showing the extent of damage in the Sumy region*

Unlike natural forest fires or the burning of dry vegetation, which typically have a random spatial distribution or spread frontally depending on wind direction, the recorded hotspots form dense areas of damage. This indicates systematic and massive artillery shelling, the use of multiple launch rocket systems, and airstrikes, which generate multiple point fires and severe destruction within a limited area.

To assess the long-term impact on the environment, a multi-temporal vegetation damage and loss severity analysis (2021 vs. 2025, June 1 – August 31) was conducted using the Normalized Burn Ratio (NBR) (Fig. 3). According to the classification, dark green indicates normal or unchanged vegetation, while light green and yellow represent areas with low to moderate damage. Orange and red zones highlight areas of high damage and severe or complete loss of vegetation directly caused by military actions and explosions.



a) *b)* *c)* *d)*

Figure 3. *Destroyed vegetation in the territory of a) the Seredyna-Buda territorial community; b) the Bilopillyalya territorial community; c) the Trostyanets territorial community; d) the Velyka Pysarivka territorial community*

A bitemporal analysis of the NDVI revealed two opposing ecological trends. In the Seredyna-Buda and Bilopillya communities, a decrease in the average index value was recorded, which is a direct consequence of biomass destruction by fires and mechanical damage to the soil caused by explosions ("bomb turbulence"). In contrast, the Velyka Pysarivka and Trostyanets communities recorded an abnormal increase in the vegetation index - a phenomenon of secondary succession. Due to landmines, significant areas of arable land have been taken out of agricultural use, where dense wild vegetation generates a higher and more stable NDVI value than agricultural crops. In the Trostyanets community, an additional factor is the cessation of sanitary logging in the forests.

The Trostyanets community recorded the largest increase in NDVI, at 0.029, and the Velyka Pysarivka community also shows positive trends. In contrast, the Seredyna-Buda community saw the most significant decline, at 0.023, while the Bilopillya community experienced a slight deterioration of only 0.002.

Across Sumy Region, 672,683 hectares – 28 % of the region's total area - have been affected by fire and explosions. The results of the analysis broken down by the region's communities under study are presented in Table 1.

Table 1. *Fire damage by local communities in Sumy Region*

Local community	Total area (ha)	Area affected (ha)	%	Burned forest (ha)
Seredyna-Buda	59 090	43 406	73.5	23 146
Bilopillyalya	54 047	27 416	50.7	5 242
Velyka Pysarivka	51 179	21 878	42.7	4 431
Trostyanets	78 701	5 517	7.0	1 937

The Seredino-Budsk community suffered the most catastrophic damage: approximately 73.5% of its territory was affected by fire. Over 23,000 hectares of coniferous forest were destroyed. Extinguishing such fires is virtually impossible due to landmines and constant shelling. In the Bilopillya and Velyka Pysarivka communities, the war's main impact was on agricultural land (18,337 ha and 13,762 ha, respectively), causing significant damage to the agricultural sector. The Trostyanets community has the lowest damage rate (7%), as it was in the active combat zone for only about one month and is located relatively farther from the border.

Conclusions

The integration of NASA FIRMS (VIIRS/MODIS), ESA WorldCover, and Sentinel-2 data within the Google Earth Engine cloud platform provides a reliable, automated methodology for monitoring environmental conditions and mapping burned areas and vegetation loss in active conflict zones where ground access is impossible. Research indicates that more than a quarter of the territory of Sumy Region (28%, or 672,683 hectares) has been directly affected by fire and explosions as a result of hostilities since February 2022. The most critical losses are concentrated in the forested border communities of the region: in the Seredyna-Buda territorial community, 73.5% of the territory has been affected by fire, and over 23,000 hectares of forest have been destroyed. In the agricultural communities (Bilopillya and Velyka Pysarivka), the main losses were suffered by farmland - over 32,000 hectares of arable land in total. NDVI analysis showed that the ecological consequences extend beyond the immediate fire damage: secondary succession on fields left fallow due to landmines creates a false signal of recovery, masking the loss of productive agricultural land. The algorithm used in the study serves as a reproducible framework for monitoring the state of the environment and its components, documenting ecocide, mapping and calculating damage and losses, and planning evidence-based restoration of war-affected territories.

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