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Geospatial Modelling of Conflict-Induced Urban Landscape Degradation Based on Sentinel-2 Imagery

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SUMMARY

Nowadays, urban studies increasingly rely on Earth remote sensing (ERS) methods for operational monitoring of changes in urban landscapes. Geoinformation modeling of urban landscape damage becomes especially important under crisis conditions, military actions, and technogenic disasters However, existing damage assessment methods are often oriented toward commercial ultra-high-resolution satellite imagery, which is costly. The main challenge is adapting free Sentinel-2 satellite data (10 m per pixel) for detecting building destruction and green-space degradation in the urban landscape structure caused by military actions. The purpose of the study is to substantiate and verify a methodology for geoinformation modeling of urban landscape damage based on Sentinel-2 multispectral data for preliminary damage assessment and calculation of losses caused by the war. The research methodology is based on the use of QGIS, Google Earth Engine (GEE), and the calculation of spectral indices. In particular, the normalized difference vegetation index (NDVI) was applied to detect damage to park areas. Building damage detection was performed using differences in the normalized difference built-up index (NDBI). Model reliability was assessed through comparative spatial analysis with OSM data and the UNOSAT Damage Assessment. The result of the study is the generation of geoimages of urban landscape destruction in the city of Mariupol, with zones identified by degree of damage. The developed algorithm allows rapid acquisition of objective data for targeted damage assessment and post-war urban recovery strategies.

Keywords: Urban landscapes; Destruction; Armed aggression; GIS; RS; Land-cover; Land-use; Sentinel-2; Classification.

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Introduction

Under current wartime conditions, the landscapes of Ukraine's territory are undergoing transformations due to military impact. Significant disturbances are associated with the destruction of hydraulic engineering structures, in particular ponds and reservoirs (Malik et al., 2025), which leads to changes in the hydrological regime and destabilization of adjacent territories. An additional factor of degradation is the spread of large-scale wildfires (Tomchenko et al., 2025), which cause loss of vegetation cover, deterioration of soil properties, and increased vulnerability to erosion processes (Orlenko et al., 2024).

The combined effect of these factors leads to ecosystem disruption (Popov et al., 2021). In this regard, there is a growing need for the development and application of modern Earth remote sensing methods for the effective identification, mapping, and monitoring of landscape damage under wartime conditions (Bialyi et al., 2026). Cities adjacent to the line of combat contact have suffered particularly severe destruction during the Russian-Ukrainian war, since the beginning of armed aggression in 2014 and especially after the full-scale invasion of 2022-2026.

Researchers (Hou et al., 2024) report the use of TKDS-PtNet - a model for detecting urban destruction that combines temporal knowledge with a transformer-based pixel network for analyzing remote sensing data. The method uses multi-temporal sequences of patches and temporal-change regularization, accounting for the irreversibility of destruction in war zones. The model works even with medium-resolution data (such as Sentinel-2), overcoming the problem of limited detail and class imbalance. Compared with other approaches, it significantly improves the accuracy of destruction identification, as confirmed by examples from cities in Syria and Ukraine.

Researchers (Aimaiti et al., 2022) assessed destruction in Kyiv and its suburbs in 2022 using Sentinel-1 and Sentinel-2 data; the joint use of radar and optical geoimages made it possible to identify 58% of damaged buildings.

The purpose of the study is to substantiate and verify a methodology for geoinformation modeling of urban landscape damage based on Sentinel-2 multispectral data, in particular, the spatial distribution and degree of building destruction in Mariupol, using the Google Earth Engine (GEE) cloud platform (Google Earth Engine, n.d.) to form a basis for forensic and financial assessment of property damage.

Method and Theory

The study was conducted for the critically damaged area of Mariupol. Time series of Sentinel-2 Surface Reflectance satellite imagery (10 m resolution) were used for two periods: before the full-scale invasion (May-September 2021) and after massive destruction (June-October 2023). To reduce the influence of atmospheric interference, the QA60 cloud-masking algorithm was applied and median composites were constructed. The assessment of landscape transformation was based on the analysis of the dynamics of three indices: the normalized difference built-up index (NDBI), the vegetation index (NDVI), and the modified normalized difference water index (MNDWI).

The normalized difference built-up index (NDBI) is used to identify anthropogenic objects, artificial surfaces (asphalt, concrete), and bare soil. It is based on the fact that the reflectance of built-up areas in the shortwave infrared range (SWIR) is higher than in the near-infrared (NIR). For Sentinel-2 it is calculated using formula (1):

$$NDBI = (B11 - B8) / (B11 + B8) \tag{1}$$

where: B11 – SWIR-1 (1610 nm), B8 – NIR (842 nm).

The normalized difference vegetation index (NDVI) is a standard index for assessing the quantity and condition of photosynthetically active biomass (green vegetation). Vegetation actively absorbs visible red light (Red) and strongly reflects near-infrared (NIR). For Sentinel-2 it is calculated using formula (2):

$$NDVI = (B8 - B4)/(B8 + B4) \quad (2)$$

where: B8 – NIR (842 nm), B4 – Red (665 nm).

The modified normalized difference water index (MNDWI) is used to identify open water surfaces and to mask shadows (from terrain or high-rise buildings), which other indices may erroneously interpret as built-up areas. It uses the green channel (Green) instead of NIR, allowing better separation of water and urban development. For Sentinel-2 it is calculated using formula (3):

$$MNDWI = (B3 - B11)/(B3 + B11) \quad (3)$$

where: B3 – Green (560 nm), B11 – SWIR-1 (1610 nm).

In the context of destruction research, these three indices work together: a positive difference ($\Delta NDBI > 0$) signals the destruction of intact structures, the appearance of concrete rubble, and exposed reinforcement (increased brightness in SWIR). A negative difference ($\Delta NDVI < 0$) confirms the destruction of the "green" elements of the urban landscape due to shelling and fires. MNDWI helps exclude the waters of the Sea of Azov and the Kalmius River, which border the study area, from the analysis. The study additionally incorporates: a) open building-location data from OpenStreetMap to refine building destruction; b) a point layer of building damage in Mariupol based on very-high-resolution satellite imagery — the UNOSAT Damage Assessment (United Nations Satellite Centre, 2022).

Results

The city of Mariupol is located in Donetsk region, on territory currently under occupation, and has suffered severe destruction during hostilities. For the use of Earth remote sensing data, the landscape of Mariupol is a complex object of study. Massive artillery shelling and airstrikes caused a radical transformation of the anthropogenic environment. In spring 2022, when Russian forces besieged the city, the residential districts suffered particularly critical damage. The collapse of metal and reinforced-concrete structures occurred, resulting in large quantities of construction debris and scrap metal.

In spectral analysis, this caused a sharp local increase in the built-up index (NDBI) due to the high reflectance of concrete and metal debris in the shortwave infrared range (SWIR, band B11). Large-scale fires, direct hits, and prolonged lack of maintenance led to massive death or burning of green vegetation. This is captured through a decrease in the vegetation index NDVI ($\Delta NDVI < -0.15 \ldots -0.25$). Residential development (especially panel apartment blocks) was transformed into a mixed type of surface cover (concrete dust, brick, bare soil), which complicates classical per-pixel classification due to the "mixed pixels" effect in medium-resolution Sentinel-2 imagery (10 m).

The city currently remains under temporary occupation, making traditional ground-based monitoring (inspections, instrumental building surveys, geodetic surveying) impossible. The developed algorithm made it possible to differentiate the urban territory by levels of destruction: from minor changes to complete destruction of objects. Owing to the degradation of vegetation cover and the change in spectral brightness of destroyed reinforced-concrete structures in the SWIR range, the model localized the damage zones (Figure 1). The results were exported in GeoTIFF format for further validation in GIS.

Figure 1. a. Result of damage classification based on Sentinel-2 Surface Reflectance data. b. Study area. The map shows temporarily occupied territories in red (KMZmap, 2026; Free Map Tools, n.d.)

The use of the NDBI index for assessing war-related destruction has a specific dual character (the "artificial-surface damage paradox"), which distinguishes it from classical urbanization monitoring. On one hand, catastrophic destruction of capital structures and industrial facilities leads to an increase in the difference index (ΔNDBI > 0). This is caused by the formation of continuous rubble made of concrete and brick, and the exposure of internal metal structures, which have high reflectance in the shortwave infrared range (SWIR, band B11 of Sentinel-2). On the other hand, in cases of complete burning of buildings down to ash, or the mixing of rubble with moist soil, a drop in the index is observed (ΔNDBI < 0). To overcome this paradox and improve modeling accuracy, an integrated approach was introduced: combining dNDBI with the difference vegetation index (ΔNDVI < 0). Since any destruction of the anthropogenic landscape is accompanied by simultaneous destruction or burning of intra-block greenery, analyzing both indices together makes it possible to compensate for spectral anomalies and ensures verified localization of zones with varying degrees of destruction (Figure 2).

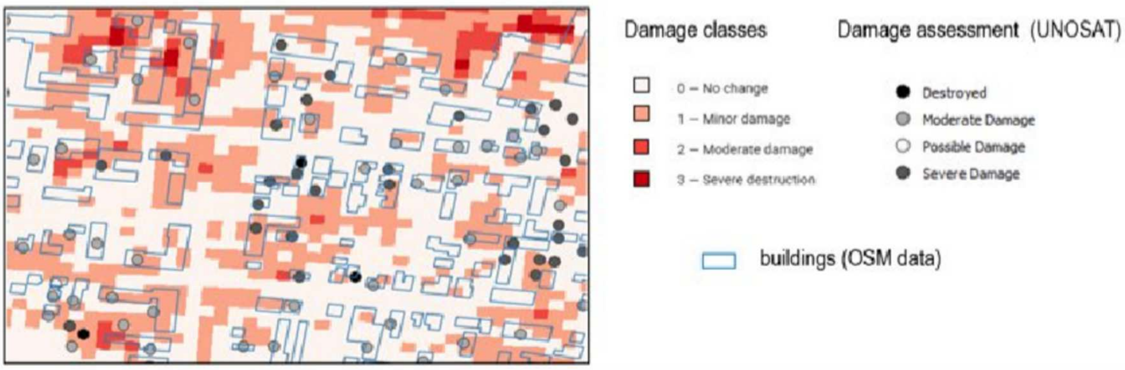

Figure 2. Comparison of the damage layer with the UNOSAT Damage Assessment point layer (UNOSAT, 2022) and the OSM building layer (OpenStreetMap contributors, 2026)

Open UNOSAT data and OSM buildings (OpenStreetMap contributors, 2026) were used as a control sample. Building outlines and the UNOSAT Damage Assessment point layer (United Nations Satellite Centre, 2022) are shown against the background of the urban-landscape damage layer calculated in this study. Visual analysis shows agreement between the damage zones obtained in this work and the UNOSAT data. Where such agreement is absent, it can be assumed that this reflects the detection of damage to green vegetation between buildings.

Conclusions

A methodology for rapid monitoring of war-related urban-landscape destruction based on threshold classification of difference indices (ΔNDBI and ΔNDVI) using Sentinel-2 multispectral data was developed and implemented in the Google Earth Engine environment. Quantitative analysis of the test polygon (63.42 ha) showed that 73.75% (46.77 ha) of the territory retained stable spectral characteristics (Class 0), i.e., did not suffer significant damage. Varying degrees of damage affected 26.25% of the land: minor changes (Class 1) were found on 15.02 ha (23.68%), moderate structural damage (Class 2) on 1.36 ha (2.14%), and epicenters of severe destruction and continuous rubble (Class 3) were localized on 0.27 ha (0.43%). We believe that the integration of ΔNDBI and ΔNDVI compensates for the optical anomalies of damaged artificial surfaces. The identified areas of severe destruction partially correspond to epicenters of direct fire damage, which may indicate the sensitivity of the developed cloud-based model for rapid urban monitoring. The proposed approach is scalable and can be recommended for preliminary remote assessment of damage and recovery planning in other urbanized territories.

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