GeoTerrace-2026-039

Identification of Destroyed and Damaged Residential Buildings in the City of Mariupol Using Sentinel-2 Satellite Imagery

***A. Prokopchuk, O. Yanchuk, A. Kibysh, P. Bilchuk**
(National University of Water and Environmental Engineering)

SUMMARY

The full-scale war in Ukraine has caused extensive destruction of residential areas, creating an urgent need for rapid damage assessment using remote sensing techniques. The aim of this study is to assess the extent of destruction and damage to residential buildings in the city of Mariupol using Sentinel-2 satellite imagery. The study area covers the territory of Mariupol, which experienced severe destruction during the military operations in 2022. Sentinel-2 satellite images acquired before the full-scale invasion and after the end of the active phase of hostilities were used for the analysis. Data preprocessing included clipping the imagery to the study area boundary and generating multispectral composites. Damaged areas were identified through supervised image classification using a training dataset developed from the spectral characteristics of the main land cover classes. Subsequent spatial analysis made it possible to identify residential buildings located within the detected damage zones and to estimate their number by the city's administrative districts. The results indicate that, as of May 8, 2022, a total of 21,243 destroyed or damaged residential buildings were identified, accounting for 45.89% of the total residential building stock. The Left Bank and Prymorskyi districts experienced the most severe destruction. Comparison of the obtained results with official data confirmed their overall agreement regarding the scale of the damage. The proposed methodology can be applied for rapid monitoring of the consequences of military operations, damage assessment, and decision support during the recovery of affected areas using open-access satellite imagery.

Keywords: Sentinel-2; Remote sensing; Mariupol; Residential buildings; Building destruction; russian armed aggression.

Corresponding Author: a.v.prokopchuk@nuwm.edu.ua

Introduction

The full-scale war in Ukraine has caused extensive destruction of residential areas and infrastructure. Rapid assessment of such damage is essential for documenting the consequences of military operations, planning the recovery of affected areas, estimating economic losses, and monitoring changes in temporarily occupied territories, where field surveys are either impossible or severely restricted.

Under these conditions, remote sensing has become one of the most effective sources of spatial information. In particular, multispectral imagery acquired by the Sentinel-2 satellite constellation operating within the Copernicus Programme provides valuable data for damage assessment (European Space Agency..., n.d.).

The aim of this study is to assess the extent of destruction and damage to residential buildings in the city of Mariupol using Sentinel-2 satellite imagery. The assessment is based on supervised classification and spatial analysis methods implemented in a geographic information system (GIS) environment.

Method and Theory

The identification of damaged and destroyed residential buildings was carried out using the methodology shown in Figure 1. The proposed workflow is based on the analysis of Sentinel-2 satellite imagery acquired before and after the large-scale destruction of the urban area of Mariupol. The overall research framework consists of four main stages (Figure 1): (1) acquisition of Sentinel-2 satellite imagery and vector data representing the locations of buildings and structures; (2) data preprocessing, including clipping the imagery to the area of interest and generating color composite images; (3) image classification, comprising unsupervised classification, preparation of the training dataset, generation of spectral signatures, and supervised classification; and (4) identification of destroyed and damaged residential buildings using spatial analysis techniques.

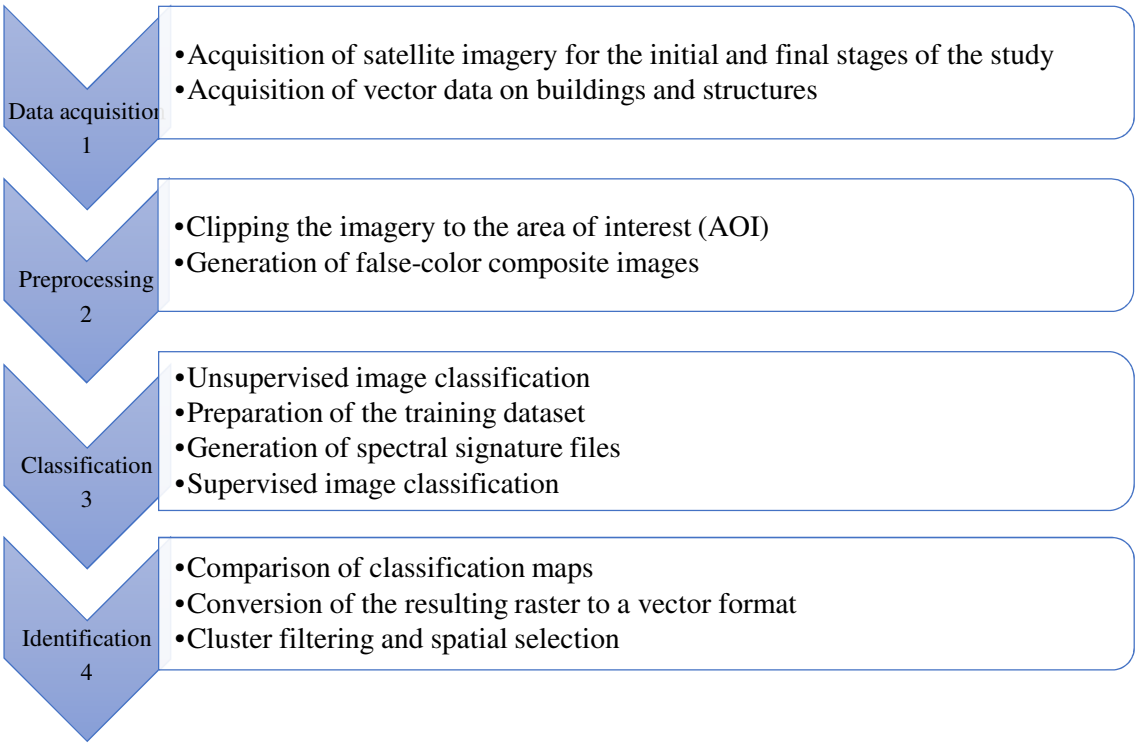


Figure 1. *Methodology for the Identification of Destroyed Buildings and Structures*

The study was conducted for the territory of the city of Mariupol (Ukraine), which suffered extensive destruction during the active phase of military operations in 2022. Two Sentinel-2 satellite images (S2MSI2A, atmospherically corrected MSI data) were used for the analysis: the first was acquired before the outbreak of the full-scale war (July 12, 2021), and the second after the end of the active phase of urban destruction (May 8, 2022). To ensure the reliability of the spectral analysis, images with minimal cloud cover were selected. In addition, vector data representing the city boundary and residential buildings were downloaded from the OpenStreetMap database (OpenStreetMap, n.d.) using the QuickOSM plugin (QuickOSM, n.d.) in QGIS.

Satellite data preprocessing included clipping the imagery to the study area boundary and generating false-color composite images.

At the classification stage, unsupervised classification was performed using the K-Means and ISODATA algorithms (K-Means Clustering, 2021; Theodoridis & Koutroumbas, 2009). The resulting clusters were used to identify spectrally homogeneous areas. These classification results were subsequently employed to develop a representative training dataset for supervised classification.

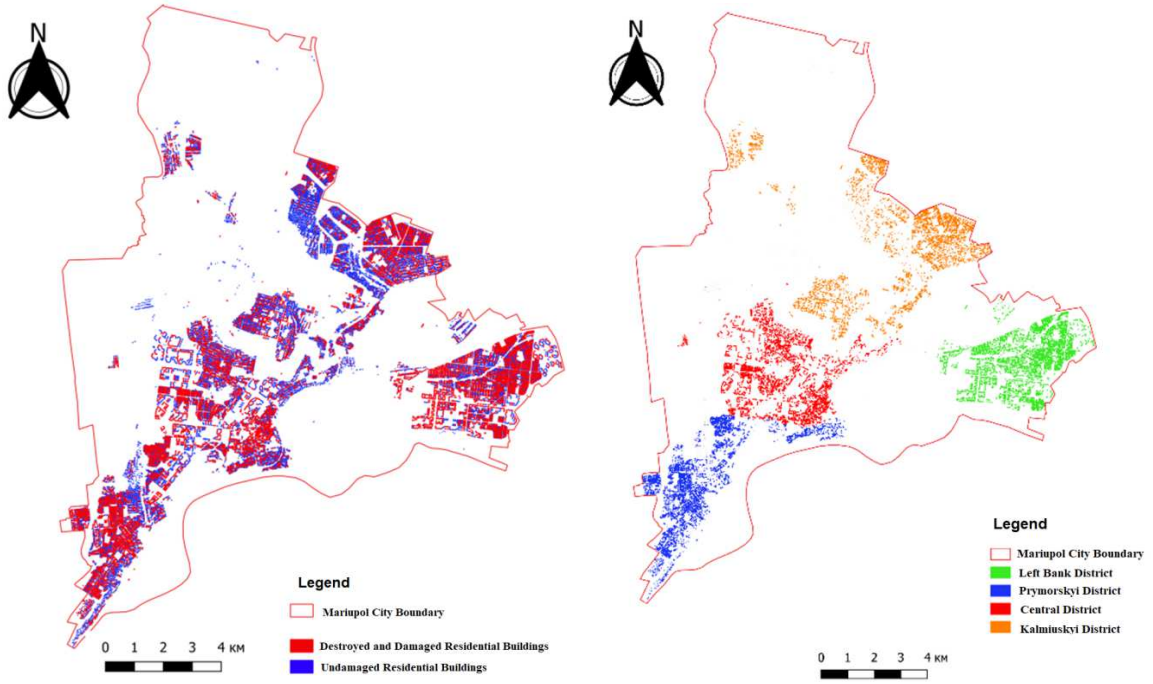
For the supervised classification, the imagery classified using the K-Means algorithm was selected. Supervised classification was performed separately for each satellite image using training polygons representing the main land cover classes, including low-rise and high-rise residential buildings, industrial facilities, grassland, trees, road networks, and water bodies. To ensure the comparability of the results for both acquisition dates, the same methodology was applied for the preparation of the training dataset and the classification procedure. Training polygons were delineated so that they did not cross class boundaries in the classification maps produced by the unsupervised classification. During the preparation of the training dataset, high-resolution satellite imagery available through the Google Maps and Bing Maps mapping services was also used as reference data.

After the supervised classification, the classes corresponding to destroyed and damaged buildings were merged by raster reclassification. The classification maps for the two acquisition dates were then compared to identify newly damaged areas using raster differencing implemented with the Raster Calculator. The resulting raster was converted into vector format, after which a spatial overlay analysis was performed with the residential building layer. Buildings intersecting the polygons of detected damage were classified as destroyed or severely damaged.

At the final stage, the identified buildings were grouped by the administrative districts of Mariupol to determine both the absolute number and the relative proportion of destroyed residential buildings within each district.

Results

The supervised classification made it possible to distinguish the main land cover classes and to identify a separate class representing damaged areas. Spatial analysis revealed a high concentration of these areas within the residential zones of the city. The processing of Sentinel-2 satellite imagery resulted in maps showing the spatial distribution of destroyed and damaged residential areas in Mariupol. By overlaying the damage map with the vector layer of residential buildings, buildings located within the detected damage zones were identified (Figure 2a). In total, 21,243 destroyed or severely damaged residential buildings were identified across the city, accounting for 45.89% of the total residential building stock. The quantitative analysis showed that the largest absolute numbers of damaged buildings were recorded in the Kalmiuskyi District (5,898 buildings) and the Left Bank District (5,281 buildings) (Figure 2b, Table 1). However, in terms of the relative proportion of damaged residential buildings, the Left Bank District (61.89%) and the Prymorskyi District (50.11%) were the most severely affected. The lowest proportion of damaged residential buildings was observed in the Kalmiuskyi District (33.71%). These findings indicate substantial spatial heterogeneity in the distribution of residential building damage across the city.



a) *b)*

Figure 2. *Spatial distribution of identified damage in the city of Mariupol: a) extent of damage to residential buildings; b) distribution of destroyed and damaged residential buildings by administrative district*

Table 1. *Number of destroyed residential buildings by administrative district of Mariupol*

Administrative district	***Total number of residential buildings***	***Undamaged buildings***		***Destroyed buildings***	
Kalmiuskyi District	*17497*	*11599*	*66,29%*	*5898*	*33,71%*
Left Bank District	*8533*	*3252*	*38,11%*	*5281*	*61,89%*
Prymorskyi District	*10448*	*5212*	*49,89%*	*5236*	*50,11%*
Central District	*9818*	*4990*	*50,83%*	*4828*	*49,17%*
Total	*46296*	*25053*	*54,11%*	*21243*	*45,89%*

The identified spatial patterns are consistent with the known directions and intensity of military operations during the siege of Mariupol. The highest concentration of destroyed residential buildings was observed in districts that experienced prolonged artillery shelling and intense urban combat. According to the Mariupol City Council, "A total of 2,257 apartment buildings in Mariupol were damaged by Russian shelling. Overall, more than 50% of the city's multi-storey residential buildings were destroyed, amounting to 1,356 buildings. More than 38,000 private houses sustained various degrees of damage, of which over 11,000 were either more than 40% destroyed or completely destroyed" (Mariupol City Council, 2022). A comparison of the obtained results with the data published by the Mariupol City Council showed that the estimated numbers of damaged buildings are comparable in terms of their overall magnitude. However, the number of buildings identified in this study is somewhat lower than the official estimates. This discrepancy can be attributed to the spatial resolution of Sentinel-2 imagery (10 m), which does not allow the reliable detection of individual small buildings or minor structural damage. Nevertheless, the proposed approach provides sufficient accuracy for the rapid assessment of the extent of destruction in areas where field surveys are impossible to conduct.

Conclusion

This study identified destroyed and damaged residential buildings in the city of Mariupol based on the analysis of Sentinel-2 satellite imagery using supervised classification and spatial analysis techniques. The identification process was performed by comparing satellite images acquired before and after the outbreak of the full-scale war.

The results indicate that, as of May 8, 2022, a total of 21,243 destroyed or severely damaged residential buildings were identified, accounting for 45.89% of the total residential building stock. The most extensive destruction was observed in the Left Bank and Prymorskyi districts, whereas the Kalmiuskyi District exhibited the lowest proportion of damaged buildings. Comparison of the obtained results with the data published by the Mariupol City Council demonstrated their overall agreement regarding the extent of damage to the city's residential buildings.

The findings confirm the potential of open-access Sentinel-2 satellite imagery for the rapid assessment of urban destruction in areas where field surveys are impossible or severely restricted. The main advantage of the proposed approach is that it relies exclusively on open-access satellite data and open-source software, making it suitable for practical application without significant financial costs. However, the use of Sentinel-2 imagery with a spatial resolution of 10 m limits the detection of individual small buildings and minor structural damage. Future research should focus on the use of very high spatial resolution satellite imagery and advanced machine learning methods to improve the accuracy of damaged building identification.

References

European Space Agency. The Sentinel missions. (n.d.). Retrieved July 11, 2026, from https://www.esa.int/Applications/Observing_the_Earth/Copernicus/The_Sentinel_missions

K-Means Clustering with Equal Sized Clustersin QGIS. (2021). Retrieved July 11, 2026, from https://spatialthoughts.com/2021/01/31/equal-sized-kmeans-qgis/

Mariupolska miska rada (2022) Zaiava Mariupolskoi miskoi rady vid 22.11.2022. Retrieved July 11, 2026, from https://t.me/mariupolrada/11747

OpenStreetMap (n.d.). OpenStreetMap Foundation. Retrieved July 11, 2026, from https://www.openstreetmap.org

QuickOSM (n.d.). Retrieved July 11, 2026, from https://docs.3liz.org/QuickOSM/

Theodoridis, S., Koutroumbas, K. (2009). Chapter 14 – Clustering Algorithms III: Schemes Based on Function Optimization. In Pattern Recognition (4th ed.). Academic Press. https://doi.org/10.1016/B978-1-59749-272-0.50016-5