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Spatio-Temporal Analysis of Land-Cover Dynamics in the Makariv Territorial Hromada, 2021-2025

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SUMMARY

Monitoring land-cover dynamics is important for understanding spatial transformations of territories affected by rapid environmental and socio-economic changes. The Makariv Territorial Hromada in Kyiv Oblast was selected to assess land-cover dynamics during 2021-2025 using annual 10 m land-use/land-cover data derived from Sentinel-2 imagery. The study aimed to quantify changes in the main land-cover classes, identify dominant interclass transitions, and assess their temporal frequency. Annual raster datasets for 2021-2025 were harmonized to a common projection, extent, spatial resolution, and pixel grid. The areas and shares of seven land-cover classes were calculated each year. Post-classification comparison was used to generate transition matrices for consecutive years and for the direct 2021-2025 comparison. A change-frequency map was produced to determine how many times each pixel changed class during the study period. Crops and Trees dominated the land-cover structure throughout 2021-2025. The largest transitions occurred between Trees, Crops, and Rangeland. The recurrent Crops–Rangeland transitions may reflect changes in agricultural land use, including temporary non-use and subsequent return to cultivation, whereas Trees–Rangeland transitions may partly reflect classification uncertainty. A direct comparison between 2021 and 2025 showed that 91.6% of the territory retained the same land-cover class. The five-year frequency analysis showed that 85.1% of the territory did not change class in any annual interval, while only 2.1% changed three or four times. The results indicate overall land-cover stability combined with localized and recurrent interclass variability, highlighting the need for cautious interpretation of automatically classified annual land-cover products.

Keywords: Land cover; Sentinel-2; Land-cover change; Post-classification comparison; Change detection; Remote sensing; Spatial dynamics; Territorial hromada

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Introduction

Land-cover monitoring is one of the fundamental applications of Earth observation data for assessing spatial transformations of territories. Modern multi-year satellite products enable tracking of changes in vegetation cover, agricultural land, built-up areas, and other surface types with high spatial detail. Advances in automated satellite image classification and the application of machine-learning methods have enabled the development of global land-cover maps with a spatial resolution of 10 m and regular updates (Karra et al., 2021; Brown et al., 2022).

Post-classification comparison is widely used to analyse temporal land-cover dynamics, as it allows not only changes in the total area of individual classes to be quantified, but also the direction of transitions from one land-cover class to another to be identified (Xie & Niculescu, 2021). In Ukraine, satellite data have already been applied to assess changes in agricultural land, forest cover, and other components of the territory, including changes associated with military impacts (Skakun et al., 2019; Pyvovar et al., 2023; Kurach et al., 2023; Myroniuk et al., 2024; Kussul et al., 2025). At the same time, the assessment of local land-cover dynamics requires a consistent series of annual observations, since a direct comparison of only the initial and final years does not allow persistent transformations to be distinguished from short-term interannual variability.

This study aims to identify and quantitatively assess the spatio-temporal dynamics of land cover in the Makariv Territorial Hromada during 2021-2025 using annual Sentinel-2 10 m Land Use/Land Cover Time Series data, with particular attention to the main directions of interclass transitions and the frequency of land-cover changes.

Method and Theory

The study was based on annual raster data from the Sentinel-2 10 m Land Use/Land Cover Time Series for 2021, 2022, 2023, 2024, and 2025. The product was generated from multispectral Sentinel-2 imagery using deep-learning algorithms and has a spatial resolution of 10 m (Karra et al., 2021). Seven land-cover classes present in the study area were analyzed: Water, Trees, Flooded Vegetation (wetland vegetation), Crops, Built Area, Bare Ground, and Rangeland (areas dominated by grasses and shrubs, including pastures and other open vegetation).

The raster datasets for all years were transformed to a common UTM projection (Zone 35), with the same spatial extent, pixel size, and raster grid. Nearest-neighbour resampling was applied to preserve the categorical values of the land-cover data. A common spatial mask was used to ensure correct pixel-by-pixel comparison between annual datasets. The area used to calculate land-cover structure and interannual transition matrices was 101265.33 ha. The area of each class was calculated from the number of pixels assigned to the corresponding class code; with a pixel size of 10 × 10 m, each pixel represented 0.01 ha.

For each year, the area and proportion of individual land-cover classes were calculated. Absolute interannual change was determined as the difference in the area of a given class between two consecutive years. Post-classification comparison was used to identify the direction of land-cover transformations (Xie & Niculescu, 2021). Transition matrices were generated for the 2021-2022, 2022-2023, 2023-2024, and 2024-2025 intervals, and an additional direct comparison between 2021 and 2025 was performed. Values along the main diagonal of the matrices represented areas that retained the same land-cover class, whereas off-diagonal values represented transitions from one class to another.

Additionally, a land-cover change-frequency map was produced for the entire study period. For each pixel, the number of class changes was calculated across the four consecutive annual intervals. Five categories were distinguished: no change, one change, two changes, three changes, and four changes. A complete five-year time series was unavailable for 32.08 ha (0.03% of the study area) due to NoData values; these pixels were therefore excluded from the change-frequency analysis. The final area included in this part of the analysis was 101233.25 ha.

Results

During 2021–2025, the overall land-cover structure of the Makariv Territorial Hromada was dominated by two classes, Crops and Trees. In 2021, Crops occupied 40831.03 ha, or 40.3% of the study area, while Trees covered 40137.61 ha, or 39.6%. Rangeland accounted for 11,608.31 ha (11.5%), and Built Area for 8095.65 ha (8.0%). Water represented approximately 0.6% of the territory, whereas Flooded Vegetation and Bare Ground occupied negligible areas.

The largest interannual fluctuations were observed for Trees, Crops, and Rangeland (Table 1). Between 2021 and 2022, the area of Trees decreased by 2115.03 ha. At the same time, Crops increased by 1613.47 ha and Rangeland by 381.78 ha. In 2022-2023, the opposite trend was observed: Trees increased by 2526.08 ha, whereas Rangeland decreased by 2110.01 ha. In 2023-2024, the most pronounced changes were a decrease in Crops by 1,439.29 ha and an increase in Rangeland by 1,604.94 ha. During 2024-2025, the area of Crops increased again by 601.79 ha, while Rangeland decreased by 413.27 ha.

Table 1. *Major land-cover class transitions in the Makariv Territorial Hromada during 2021-2025, ha*

Land-cover transition	***2021-2022, ha***	***2022-2023, ha***	***2023-2024, ha***	***2024-2025, ha***
Trees → Rangeland	1892.53	357.37	705.58	648.88
Rangeland → Trees	288.73	2345.27	494.89	676.72
Crops → Rangeland	1124.30	1,587.77	2175.19	1018.38
Rangeland → Crops	2322.47	1608.03	907.30	1403.94
Trees → Crops	548.79	207.46	275.06	386.73
Crops → Trees	92.91	664.04	458.05	198.26
Crops → Built Area	297.56	352.93	245.76	198.65
Built Area → Crops	255.75	242.38	262.34	221.08

At the same time, the direct comparison between 2021 and 2025 showed that the overall changes in the areas of the main land-cover classes were considerably smaller than the individual interannual fluctuations. Over the entire study period, Trees increased by 229.45 ha, Crops by 226.43 ha, and Built Area by 80.43 ha, whereas Rangeland decreased by 536.56 ha. Thus, relatively small net changes in the total area of individual classes masked a much more intensive spatial redistribution among them. The proportion of the territory that retained the same land-cover class between consecutive years remained high. Stable areas accounted for 92.8% of the territory in 2021-2022 and 92.2% in 2022-2023. In the following periods, stability increased to 94.0% in 2023-2024 and 94.9% in 2024-2025.

A direct comparison of the initial and final states showed that, in 2025, 92,799.68 ha, or 91.6% of the territory, belonged to the same land-cover class as in 2021. The largest long-term transitions were Rangeland → Crops, covering 1900.53 ha; Crops → Rangeland, 1526.85 ha; Rangeland → Trees, 1521.24 ha; and Trees → Rangeland, 1341.17 ha. The Crops → Trees and Trees → Crops transitions covered 446.28 and 410.49 ha, respectively.

The change-frequency analysis also confirmed the predominance of stable areas (Figure 1). Across all four interannual intervals, 85.1% of the total analysed area retained the same land-cover class throughout the entire study period. One class change was recorded for 6.1% of the territory, two for 6.6%, three for 1.8%, and four for only 0.3%.

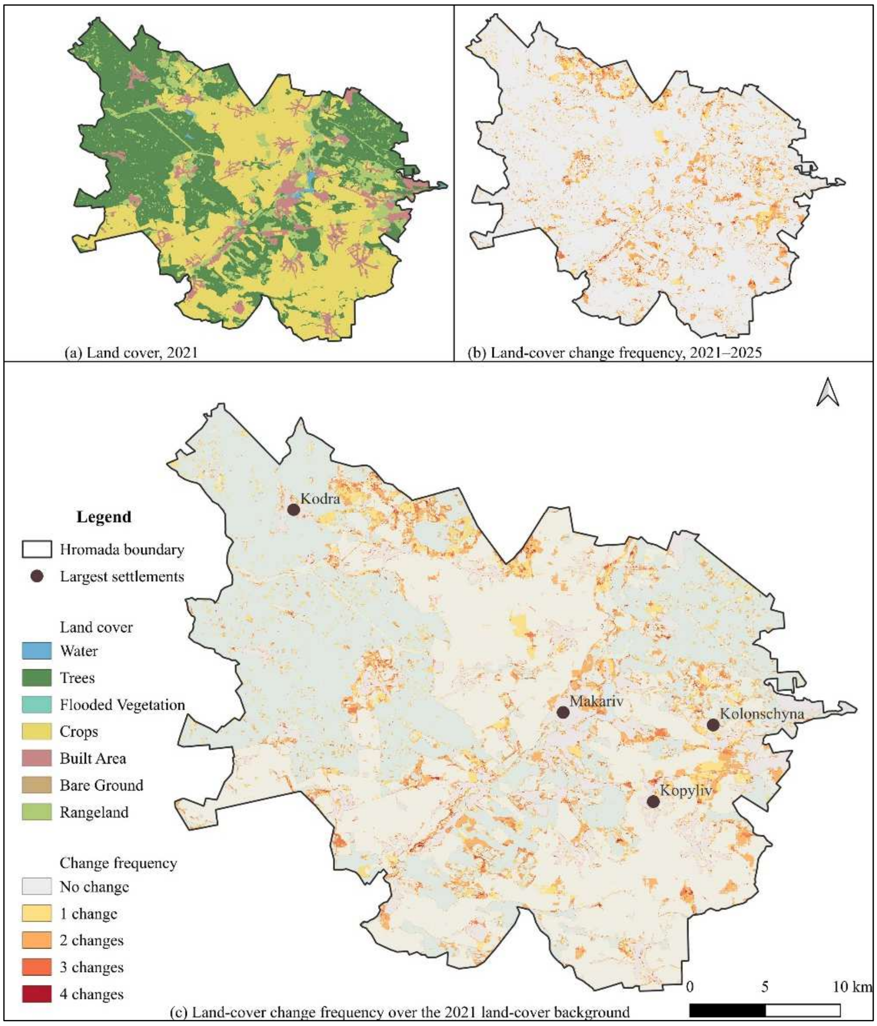

Figure 1. *Spatial distribution of land-cover change frequency in the Makariv Territorial Hromada during 2021-2025*

The substantial reciprocal transitions Trees ↔ Rangeland and Crops ↔ Rangeland indicate that an interannual change in the assigned land-cover class cannot always be interpreted as a persistent physical transformation of land cover. A particularly illustrative example is the Trees → Rangeland transition, which covered 1892.53 ha in 2021-2022, followed by an even larger reverse transition, Rangeland → Trees, covering 2345.27 ha in the subsequent interval. Similar bidirectional transitions between Crops and Rangeland were observed throughout the study period. Therefore, the results of automated classification are most appropriate for identifying areas of spatial dynamics, while determining the causes of specific changes requires additional verification using original satellite imagery or other independent data sources.

Conclusions

The analysis of annual land-cover data for 2021-2025 showed overall stability in the land-cover structure of the Makariv Territorial Hromada, while substantial interannual transitions among individual classes were also observed. The main changes were concentrated within the Trees–Crops–Rangeland system, whereas Water, Flooded Vegetation, Built Area, and Bare Ground showed considerably lower area dynamics. The most likely drivers of changes within the Crops–Rangeland system are variations in the intensity of agricultural land use, temporary non-use or abandonment of cropland, and its subsequent return to cultivation; similar processes in war-affected areas of Ukraine have been identified using satellite data in previous cited studies. Transitions between Trees and Rangeland may reflect both actual changes in tree, shrub, and grass vegetation and uncertainties associated with automated classification, since the global 10 m product is subject to classification error and class-specific accuracy may vary. Therefore, in this study, the identified transitions should be interpreted as indicators of spatial dynamics rather than as direct evidence of a specific process, including military impacts, without additional verification with original satellite imagery.

A direct comparison between 2021 and 2025 showed that 91.6% of the territory retained its initial land-cover class. At the same time, analysis of the complete five-year time series showed that 85.1% of the territory did not change class in any of the four interannual intervals. Areas with frequent changes were limited: only 3 or 4 class changes were recorded in 2.1% of the total area.

The combined analysis of class structure, interclass transition matrices, and change-frequency mapping enabled identification of both general long-term trends and short-term interannual variability. Substantial reciprocal transitions between individual classes confirm the need for cautious interpretation of automated classification results and for additional verification of areas showing the most pronounced or persistent dynamics.

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