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Long-Term Land Cover Change in Kyiv (Ukraine): A Paired Point-based Assessment Using i-Tree Canopy and Google Earth Pro

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SUMMARY

Urbanization drives progressive transformation of land cover in large cities, with direct consequences for hydrological regime, microclimatic conditions, and the ecological resilience of urban geosystems. This study quantifies land cover dynamics in Kyiv over a twenty-year period (2005–2025) by comparing two temporal cross-sections derived from an identical sample of point observations. The administrative boundary of the city was delineated in QGIS using open OpenStreetMap geodata. Classification was performed in i-Tree Canopy using a random point-sampling method (2,503 points, seven cover classes); for the retrospective analysis, identical points were exported in KML format and re-assessed against archival Google Earth Pro imagery from 2005, with reclassification restricted to points whose cover state had changed. The results indicate a decline in the combined share of vegetated cover (Tree/Shrub and Grass/Herbaceous) from 66.16% to 57.85% of the city area, most pronounced in the Grass/Herbaceous class (from 11.43% to 5.07%). The aggregate share of impervious surfaces (Impervious Buildings, Road, and Other) increased from 22.09% to 25.01%, while the area of bare soil nearly doubled (from 5.51% to 10.47%), reflecting active construction pressure on open land. The Water class remained comparatively stable (6.23–6.67%). Despite the observed decline, tree and shrub vegetation retains a dominant position within the cover structure, underscoring the substantial ecological potential of Kyiv's green infrastructure network. These findings provide an analytical basis for monitoring vegetation loss, planning green space, and guiding spatial development under conditions of intensifying anthropogenic pressure.

Keywords: Land cover change; Urban impervious surfaces; i-Tree Canopy; Remote sensing; Green infrastructure; Kyiv; Google Earth Pro; Urbanization.

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Introduction

Urbanization drives continuous transformation of land cover in large cities, altering hydrological processes, microclimatic conditions, and the ecological resilience of urban environments. Land cover structure represents one of the most informative indicators of the spatial organization of urban geosystems, as it characterizes the spatial balance between natural, semi-natural, and anthropogenically transformed surfaces. In large metropolitan areas, this balance is continuously reshaped by multiple urbanization processes, including the expansion of built-up areas, the development of transportation infrastructure, the conversion of vacant and peri-urban land, and the fragmentation of vegetation cover. The increasing proportion of impervious surfaces intensifies surface runoff, reduces soil infiltration, amplifies the urban heat island effect, and contributes to the degradation of the ecological framework provided by urban green infrastructure (Havrylenko, Tsyhanok, Shyshchenko, Samoilenko, & Bilous, 2022). These interrelated processes highlight the necessity of systematic quantitative monitoring of land cover structure as a fundamental tool for the geoecological assessment of urban environmental quality.

Within this context, comparative land cover analysis based on two temporal snapshots enables the transition from describing the current state of the urban environment to quantitatively assessing landscape transformation. Tree and shrub vegetation, herbaceous surfaces, bare soil, and water bodies constitute the natural and semi-natural components of the urban landscape, whereas buildings, roads, and other artificial surfaces represent the anthropogenic infrastructure. Changes in the balance between these groups of land cover classes serve as an important indicator of both the intensity and direction of urban spatial development (Sorokina, & Tsyhanok, 2024). Kyiv provides an appropriate case study for such an assessment, as its administrative boundaries encompass densely built-up central and residential districts, extensive forest parks (Holosiivskyi National Nature Park, Lysa Hora Regional Landscape Park, and Partyzanska Slava Regional Landscape Park), the Dnipro River valley, floodplain islands and water bodies, as well as rapidly developing construction areas. This pronounced spatial heterogeneity makes comparative land cover analysis particularly suitable for identifying differentiated patterns of urban transformation (Shyshchenko, Havrylenko, & Tsyhanok, 2020).

Method and Theory

The aim of this study was to quantitatively assess changes in the land cover structure of Kyiv over a 20-year period (2005–2025) using a paired point-based assessment approach implemented in i-Tree Canopy (i-Tree Canopy, n.d.) and Google Earth Pro (Google LLC, 2026). The study area comprised the territory of Kyiv within its official administrative boundaries. The boundary polygon was obtained in QGIS (QGIS Development Team, 2026) using the QuickOSM plugin (QuickOSM, 2026), which retrieves spatial data from the OpenStreetMap database (OpenStreetMap contributors, 2026) via the Overpass API. The resulting polygon layer was exported as an ESRI Shapefile, one of the native formats supported for data import into i-Tree Canopy. All spatial data were projected into the WGS 84 / UTM Zone 36N coordinate reference system (EPSG:32636).

Land cover classification was performed using a random point sampling approach, whose statistical basis follows the classical sampling theory for estimating proportions in a finite population (Cochran, 1977). For a binomial proportion p and sample size n, the standard error is estimated as $SE = \sqrt{(p(1-p)/n)}$. With a sample size of 2,503 points, the dominant land cover class (Tree/Shrub; $p \approx 0.53$) corresponds to an estimated standard error of approximately 1.0%, which is consistent with the observed sampling uncertainty (Table 1) and supports the adequacy of the selected sample size for regional-scale land cover assessments. Previous studies have also demonstrated that point-based sampling in i-Tree Canopy provides stable estimates for sample sizes exceeding 1,000 points across extensive urban study areas (Nowak & Greenfield, 2012), supporting its application to the Kyiv area.

Each sampling point was visually interpreted using the most recent high-resolution satellite imagery available for 2025 and assigned to one of seven land cover classes: Grass/Herbaceous (H), Impervious

Buildings (IB), Impervious Other (IO), Impervious Road (IR), Soil/Bare Ground (S), Tree/Shrub (T), and Water (W). This classification scheme corresponds to the standard i-Tree Canopy land cover classification and has also been applied in comparative assessments of 20 U.S. cities, supporting its suitability for inter-city comparisons (Nowak, & Greenfield, 2012; USDA Forest Service, 2023). It should be noted that the acquisition date of the background imagery displayed in i-Tree Canopy cannot be controlled, and differences in vegetation phenology between image acquisition dates may introduce systematic bias in the estimated proportions of the Tree/Shrub and Grass/Herbaceous classes. To minimize this source of uncertainty, all 2,503 sampling points were exported as a KML file and imported into Google Earth Pro, where the historical imagery function was used to select archive images acquired during the corresponding growing season (June–August). Historical imagery from the same vegetation period was also used for the 2005 assessment. Only those sampling points whose land cover class changed between the two observation dates were reclassified. This paired interpretation approach enabled the construction of two directly comparable datasets based on an identical random sample and a consistent land cover classification scheme, thereby eliminating variability associated with independently generated point samples. The year 2005 was selected as the baseline because Google Earth Pro provides archival satellite imagery of sufficient spatial quality for reliable visual interpretation across the study area.

Results

The classification results are presented in Table 1 and Figure 1. The overall pattern indicates a decline in the combined proportion of vegetated land cover classes accompanied by an increase in anthropogenically transformed surfaces. The combined share of the Tree/Shrub and Grass/Herbaceous classes decreased from 66.16% in 2005 to 57.85% in 2025 (Δ = −8.31%), whereas the combined proportion of the three Impervious classes increased from 22.09% to 25.01% (Δ = +2.92%). The largest decline was observed for the Grass/Herbaceous class, which decreased from 11.43% to 5.07% (Δ = −6.36%, equivalent to approximately 52.14 km²), representing the most pronounced change in the overall land cover structure. This reduction is likely attributable to the conversion of herbaceous surfaces into the Soil/Bare Ground class following vegetation removal at construction sites or their direct transformation into impervious surfaces upon completion of urban development. Although the Tree/Shrub class remained the dominant land cover category, its proportion declined by 1.95%, representing a moderate but spatially substantial reduction at the city scale.

The near doubling of the Soil/Bare Ground class, from 5.51% to 10.47% (Δ = +4.96%, corresponding to approximately 40.60 km²), likely reflects a combination of ongoing construction activities on previously undeveloped land and methodological effects associated with the lower spatial resolution of historical Google Earth Pro imagery from 2005 compared with the contemporary imagery used for the 2025 assessment. Lower image resolution increases the probability of assigning small artificial surfaces to the Soil/Bare Ground class instead of Impervious Other. In contrast, the Water class remained relatively stable within the estimated sampling uncertainty (6.23 ± 0.48% in 2005 and 6.67 ± 0.50% in 2025). The internal consistency of the results is supported by the overall land cover balance: the combined reduction of vegetated classes (ΔTree/Shrub + ΔGrass/Herbaceous ≈ −68.20 km²) closely corresponds to the combined increase in Impervious and Soil/Bare Ground classes (+23.97 km² and +40.60 km², respectively), together with a minor increase in water surfaces (+2.91 km²).

The observed trends are consistent with widely documented patterns of urban land cover transformation. According to Nowak and Greenfield (2012), the average annual decline in tree canopy across 20 U.S. cities is approximately 0.27% per year, whereas the corresponding rate for Kyiv is substantially lower, averaging approximately 0.10% per year (1.95% over the 20-year study period). This difference may be associated with the stabilizing role of protected green areas, which occupy more than 21% of the city's territory and legally restrict large-scale urban development within forested landscapes. In contrast, the pronounced decline in herbaceous surfaces and the increase in the Soil/Bare Ground class may indicate relatively intensive development pressure on unprotected open spaces.

Table 1. *Land cover composition of Kyiv in 2005 and 2025. Values are presented as the estimated percentage and area (km²) ± standard error (SE)*

Abbr.	Cover Class	2025			2005		
		Points	% Cover ± SE	Area (km²) ± SE	Points	% Cover ± SE	Area (km²) ± SE
H	Grass/Herbaceous	127	5.07 ± 0.44	41.64 ± 3.60	286	11.43 ± 0.64	93.78 ± 5.22
IB	Impervious Buildings	257	10.27 ± 0.61	84.27 ± 4.98	211	8.43 ± 0.56	69.19 ± 4.56
IO	Impervious Other	210	8.39 ± 0.55	68.86 ± 4.55	199	7.95 ± 0.54	65.25 ± 4.44
IR	Impervious Road	159	6.35 ± 0.49	52.14 ± 4.00	143	5.71 ± 0.46	46.89 ± 3.81
S	Soil/Bare Ground	262	10.47 ± 0.61	85.91 ± 5.02	138	5.51 ± 0.46	45.25 ± 3.74
T	Tree/Shrub	1321	52.78 ± 1.00	433.17 ± 8.19	1370	54.73 ± 0.99	449.23 ± 8.17
W	Water	167	6.67 ± 0.50	54.76 ± 4.09	156	6.23 ± 0.48	51.15 ± 3.97
Total		**2503**	**100.00**	**820.75**	**2503**	**100.00**	**820.75**

The findings have two principal practical implications. First, the generated reference dataset may support the calibration and validation of automated Sentinel-2 land cover classification for the entire administrative territory of Kyiv, thereby improving the temporal resolution of long-term urban monitoring. Second, the results provide a basis for comparison with the requirements of DBN B.2.2-12:2019 (including Amendment No. 1, effective from 1 January 2026), which specifies a minimum greening ratio of 25% for residential areas (Ministry for Development of Communities and Territories of Ukraine, 2025). A rigorous compliance assessment, however, requires the calculation of Tree/Shrub and Grass/Herbaceous cover exclusively within residential functional zones and therefore represents an important direction for future research.

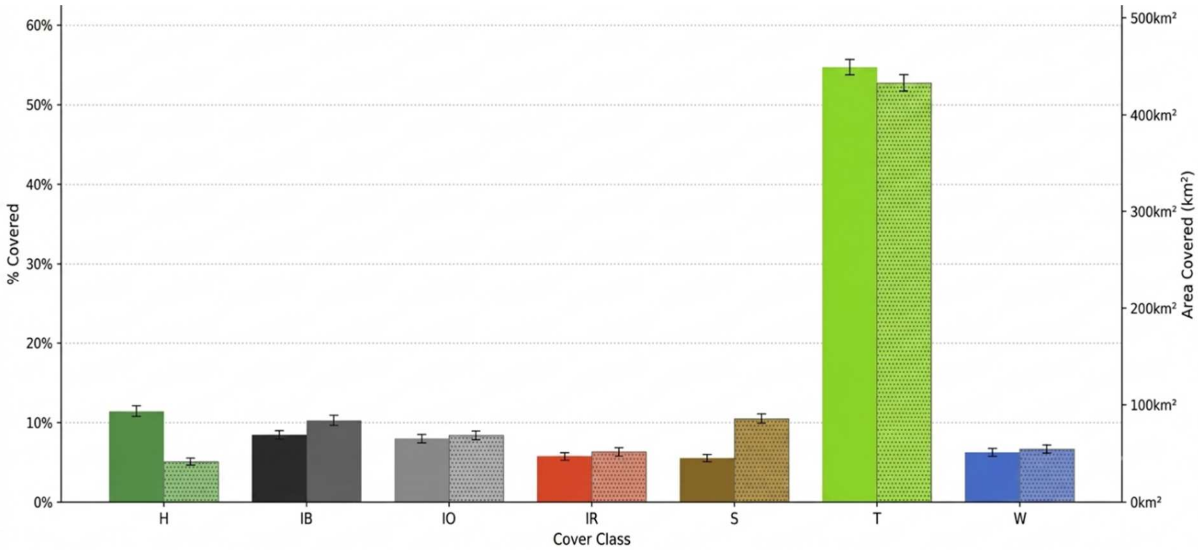

Figure 1. *Comparison of land cover composition in Kyiv between 2005 and 2025. Hatched bars correspond to the 2025 assessment. Error bars denote ±1 standard error*

Conclusions

Comparative analysis of Kyiv's land cover structure between 2005 and 2025 revealed a clear decline in vegetated land cover accompanied by a gradual increase in anthropogenically transformed surfaces, a pattern consistent with ongoing urban expansion. Despite this decline, the Tree/Shrub class remained the dominant land cover component (52.78% in 2025), indicating that Kyiv retains substantial ecological capacity supported by an extensive network of protected areas, which likely contributes to the long-term conservation of urban forest cover.

The results establish a quantitative baseline for long-term monitoring of urban land cover dynamics in Kyiv and may support urban green infrastructure planning, vegetation loss assessment, and the development of environmentally oriented spatial planning strategies under increasing anthropogenic pressure. Future methodological improvements should focus on harmonizing phenological conditions between image acquisition dates to reduce systematic uncertainty and on mapping spatial transitions among land cover classes to identify urbanization hotspots across different parts of the city.

References

Cochran, W.G. (1977). Sampling Techniques (3rd ed.). John Wiley & Sons.

Google LLC. (2026). Google Earth Pro (V 7.3) [Software]. https://earth.google.com/web/

Havrylenko, O., Tsyhanok, Ye, Shyshchenko, P., Samoilenko, V., & Bilous, L. (2022). Geoecological Monitoring of Urban Wetlands for the Purpose of their Protection (by the Case of Sovski Ponds in Kyiv). Proceedings of the 16th International Conference "Monitoring of Geological Processes and Ecological Condition of the Environment", 1–5. DOI: https://doi.org/10.3997/2214-4609.2022580011

i-Tree Canopy. (n.d.). i-Tree Tools. https://canopy.itreetools.org/survey

Ministry for Development of Communities and Territories of Ukraine. (2026). DBN B.2.2-12:2019 "Planyvannia ta zabudova terytorii". Zmina No. 1 (effective January 1, 2026). https://e-construction.gov.ua/laws_detail/3874277768581612585 [In Ukrainian].

Nowak, D.J., & Greenfield, E.J. (2012). Tree and impervious cover change in U.S. cities. Urban Forestry & Urban Greening, 11(1), 21–30. https://doi.org/10.1016/j.ufug.2011.11.005

OpenStreetMap contributors (2026). OpenStreetMap [Data set]. OpenStreetMap Foundation. Available as open data under the Open Data Commons Open Database License (ODbL) at https://www.openstreetmap.org

QGIS Development Team. (2026). QGIS Geographic Information System (Version 3.44.7) [Computer software]. Open Source Geospatial Foundation. https://qgis.org

QuickOSM. (2026). QuickOSM (Version 3.44.7) [QGIS plugin]. QGIS Plugin Repository. https://plugins.qgis.org/plugins/QuickOSM/

Shyshchenko, P., Havrylenko, O., & Tsyhanok, Ye. (2020). Protected areas under the conditions of megapolis: digression and recovery ways (on the example of Kyiv). Ukrainian Geographical Journal, 4, 49–56. https://doi.org/10.15407/ugz2020.04.049 [In Ukrainian].

USDA Forest Service. (2023). i-Tree Canopy user manual v7. U.S. Department of Agriculture, Forest Service. https://www.itreetools.org

Sorokina, L., & Tsyhanok, Ye. (2024). Analysis of the land cover structure dynamics of landscapes in the Chernobyl Nuclear Power Plant exclusion zone (methodical aspect). Proceedings of the International Conference of Young Professionals "GeoTerrace-2024", 1–5. https://doi.org/10.3997/2214-4609.2024510084