Carbon stock in Galanta municipality – methods

Land cover classification was based on aerial orthophotos (2023), airborne LiDAR point cloud data (2023) provided by UGKK, Openstreetmap data and LPIS land-use data. The orthophoto mosaic (15 cm spatial resolution) was used to derive vegetation indices, while the LiDAR point cloud (minimum density: 5 points per m2) was used to generate the Digital Terrain Model (DTM), Digital Surface Model (DSM), and a raster representing the number of LiDAR returns. Building footprints, road networks and LPIS were used to mask built-up ańd agricultral areas. Classification was performed using an object-based image analysis (OBIA) approach implemented in eCognition. Vegetation was identified using a combination of NDVI, canopy height derived from the Canopy Height Model (CHM), and the number of LiDAR returns, which improved the classification of trees, shrubs, and grass, particularly in shaded areas. The tree class was classified into individual crowns using watershed segmentation.

The Canopy Height Model (CHM) was generated by subtracting the Digital Terrain Model (DTM) from the Digital Surface Model (DSM) (CHM = DSM − DTM), both derived from the LiDAR point cloud. The DTM and DSM were created in eCognition following the methodology proposed by Staengel (2021) at a spatial resolution of 15 cm. The workflow consisted of rasterizing the LiDAR point cloud, filling small gaps using morphological filtering, and interpolating larger gaps using inverse distance weighting (IDW) for the DSM and linear interpolation for the DTM. The resulting CHM was used to calculate the mean canopy height for each vegetation polygon. Mean canopy height, together with crown projection area, served as input variables for estimating above-ground and below-ground biomass carbon stocks.

Classification schema consists of five classes:

- Other (artificial surfaces, water, bare soil…)
- Grass
- Arable land
- Shrubs
- Trees

Output vector layer (SHP) contains carbon stock in tC/ha separately for three primary carbon pools:

- AGB (above-ground biomass)
- BGB (below-ground biomass)
- SOC (soil carbon)

1. Calculation of carbon stock for other surfaces

Other LC classes have been removed from the output layer.

2. Calculation of carbon stock in biomass carbon pools for grass

Values were adopted from Kizeková et al. (2019), who quantified carbon stocks in permanent grasslands across Slovakia. Specifically, values derived from the study site Nacina Ves were selected. This locality exhibits the closest ecological similarity to our study area, as it is set on the agricultural lowland.

- C_{AB} = 2.56 tC/ha
- C_{BB} = 3.86 tC/ha

3. Calculation of carbon stock in biomass carbon pools for arable land

C_{AB} was not assessed for arable land because annual crops constitute a short-lived biomass pool that is harvested and replaced within annual crop rotations.

C_{BB} value was derived from the dataset of harmonized global maps of above and belowground biomass carbon density in the year 2010 introduced by Spawn et al. (2020). Zonal statistics tool was used to calculate the mean below-ground carbon stock for the areas classified as arable land.

4. Calculation of carbon stock in biomass carbon pools for shrubs

For each polygon of shrubs, a mean height (H) and crown projection area (A) was derived from the Canopy Height Model.

Carbon stock for AGB was calculated as follows:

$$C_{AB} = \frac{a \times A^{b_1} \times H^{b_2} \times CF}{1000} \times \frac{10000}{A}$$

Carbon stock for BGB was calculated as follows:

$$C_{BB} = \frac{a \times A^{b_1} \times H^{b_2} \times CF \times R}{1000} \times \frac{10000}{A}$$

Where:

- a = 0.43
- b_1 = 0.604
- b_2 = 0.85
- CF (carbon fraction of dry matter [t dry matter^{-1}] = 0.5
- R (ratio of below-ground biomass to above-ground biomass [t dry matter of BGB / t dry matter of AGB] = 0.26

Coefficients a, b_1 and b_2 were established in accordance with the Pajtík et al. 2025. R was based on the Chow and Rolfe (1989) and CF was based on the Cairns et al. 1997.

5. Calculation of carbon stock in biomass carbon pools for trees

Tree biomass could not be calculated directly because a detailed tree inventory was not available for Galanta municipality. Therefore, tree biomass was estimated from a canopy height model (CHM) derived from the LiDAR point cloud acquired during the second cycle of ZBGIS airborne laser scanning. Points classified as low and high vegetation were extracted from the point cloud and used to generate a CHM with a spatial resolution of 0.25 m. Tree crowns and tree groups were subsequently delineated from the CHM using the watershed segmentation algorithm implemented in eCognition Developer. For each tree crown/tree group segment, the following statistical attributes were calculated: maximum height (z_max), mean height (z_mean), median height (z_median), height standard deviation (z_stdev), sum of heights (z_sum), and crown area.

The prediction model was developed using data from a detailed tree inventory in the Bratislava–Staré Mesto district. The inventory contained 3,628 trees located within 34 sample plots, with tree positions recorded as trunk coordinates. Carbon storage for individual trees was calculated using the i-Tree Eco software (Nowak, 2021). In i-Tree Eco, carbon storage is estimated as 50% of the total tree biomass (Chow and Rolfe, 1989). Total biomass is calculated from species-specific allometric equations using tree species, diameter at breast height (DBH), total tree height, crown dieback, and crown light exposure as input variables. For deciduous trees, only the carbon stored in woody biomass is considered because foliage is shed annually. To avoid overestimation for exceptionally large trees, the stored carbon is capped at 7,500 kg per tree.

A CHM derived from the ZBGIS lidar data was also generated for the Bratislava–Staré Mesto study area, where tree crowns and tree groups were delineated using the same workflow. A total of 922 crown segments could be uniquely matched to inventoried tree trunks and were therefore used for model development. Carbon storage values calculated in i-Tree Eco served as the response variable, while the CHM-derived statistical attributes represented the explanatory variables. The Random Forest model was developed in ArcGIS Pro using 500 decision trees, with an average tree depth of 19. Twenty percent of the data were reserved for independent model validation. The resulting model explained 91% of the variance in the training dataset and 70% of the variance in the validation dataset. Among the explanatory variables, *z_sum* was identified as the most important predictor. This variable represents the sum of CHM pixel heights within each crown segment and can be considered a proxy for canopy volume, which explains its strong relationship with carbon storage.

The trained model was subsequently applied to estimate carbon storage in tree vegetation within the city of Galanta.

6. Calculation of soil carbon

SOC in the <30 cm depth was calculated as follows:

$$SOC = SOC_{REF} \times F_{LU} \times F_{MG} \times F_I$$

In the case of grass, shrubs and trees, factors were established as follows:

- F_{LU} (Stock change factor for land-use systems) = 1
- F_{MG} (Management factor) = 1
- F_I (Input factor) = 1

In the case of arable land, factors were established as follows:

- F_{LU} = 0.8
- F_{MG} = 1
- F_I = 1

SOC was not calculated for build-up areas (according to the BPEJ layer).

Reference values (SOC_{REF}) were based on the spatially corresponding soil type, obtained from forest soils and BPEJ vector datasets.

In the case of high activity clay soil (e.g., chernozems, mollisols, fluvisols):

- SOC_{REF} = 38

In the case of wetlands (e.g., gleysols):

- SOC_{REF} = 88

All the used factors and reference values were introduced in the IPCC (2006). The location of the study area in the temperate dry climatic zone was reflected.

In the case of factors for arable land, we chose the values for:

- landscape that represents the continuously managed area with predominantly annual crops (F_{LU})
- local management that causes substantial soil disturbance with full inversion and frequent tillage operations crops (F_{MG})
- applied local management that features annual cropping with cereals where all crop residues are returned to the field (F_I)

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