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MONITORING THE CONDITION OF URBAN GREEN SPACES THROUGH TIME-SERIES SATELLITE IMAGERY

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Abstract: Urban green spaces are essential for maintaining city livability, particularly under increasing climate extremes such as prolonged droughts. This study evaluates the condition and changes of green areas in Mezőkövesd between 2017 and 2024 using Sentinel-2 satellite imagery. NDVI and the Green Surface Intensity Index (ZFI) were used to assess vegetation health and spatial distribution. Findings reveal a significant decline in vegetation from 2022 due to drought, highlighting the vulnerability of urban greenery. Although the average per capita green space exceeds WHO minimums, spatial disparities exist. Accessibility analyses show that several areas lack nearby recreational green spaces. Targeted greening and climate-resilient planting are recommended.

***Keywords**: NDVI, Green Space Index, GIS, Sentinel-2*

1. INTRODUCTION

Urban green spaces play a key role in maintaining the livability of settlements, as they contribute to the regulation of the microclimate, the improvement of air quality, the reduction of noise pollution, and also provide recreational and aesthetic value. However, the increasingly frequent and severe weather extremes caused by climate change – such as prolonged droughts – pose a serious threat to the condition and extent of urban vegetation. For this reason, continuous monitoring of green spaces is of paramount importance not only in large cities but also in medium-sized towns such as Mezőkövesd.

Green space refers to the vegetated part of a given area or settlement (e.g., public parks, playgrounds, cemeteries, themed gardens, groves, tree-lined avenues, etc.) and plays an important ecological and aesthetic role, even on private properties. In contrast, "green area" is a specific land-use category defined in urban development plans, referring to public spaces primarily covered with vegetation and not intended for construction.

The aim of our research is to provide a comprehensive overview of the condition and changes of green spaces in Mezőkövesd between 2017 and 2024. For the analysis, we used advanced remote sensing techniques: we processed NDVI (Normalized Difference Vegetation Index) values derived from Sentinel-2 satellite data and analyzed ZFI (Green Space Intensity Index) values to map the changes observed during the vegetation periods. We also assessed the amount of green area per capita and its accessibility. The results reflect not only the current state of green infrastructure but can also serve as a foundation for future urban planning and green infrastructure development strategies.

Since the 1990s, as part of the study of urbanization processes, the analysis of green spaces and green areas as components of urban land use has come into focus. Major research themes include urban forests, urban heat islands, urban ecology, emissions (air pollution), urban structure, mental health, quality of life, well-being, and the concept of the "Green City" (Farkas et al., 2023).

The maintenance and availability of urban green areas for residents are an important part of current urban planning in Hungary and of environmental impact assessments in cities. GIS-based geoinformatics systems provide excellent tools for mapping green areas, establishing monitoring systems, tracking changes in condition, and identifying environmental problems.

The growth and transformation of cities involve not only changes in population numbers but also the scale and direction of urban spatial expansion. Both processes are closely linked to the mapping and characterization of green areas, for which the analysis of time-series satellite images is essential. In the rapidly changing urban world, researchers focus both on rapidly growing cities (Rafiee et al., 2009; Deng et al., 2019) and on the challenges of creating sustainable urban environments (Fórián & Hagymássy, 2009; Bokhari et al., 2022; Szigeti & Czédli, 2022; Siskáné & Szepesi, 2022) using this methodology. One of the challenges for researchers is to adapt the design of green areas to the characteristics of the urban environment, both in terms of plant species and spatial layout (Kisvarga & Horotán, 2023).

While the most dynamic changes can be observed in global and large-scale cities, increasing attention is being paid to the study of small and medium-sized towns, and today, municipal governments also recognize the importance of conducting such analyses (e.g., Bábolna 2014; Salgótarján 2024).

2. Geography of Mezőkövesd

Mezőkövesd is located at the southern foothills of the Bükk Mountains, at the junction of the Great Hungarian Plain and the North Hungarian Mountains, within two distinct natural geographic micro-regions: Bükkalja and Borsodi-Mezőség. The town lies on the coalesced alluvial fans of the Ostoros, Kánya, and Hór creeks. The study area has a warm and dry climate. The number of sunshine hours ranges between 1950 and 2000 per year. The annual mean temperature is around 10 °C, although climate models project a possible increase of up to 3 °C in the coming decades. Annual precipitation varies between 500 and 550 mm (Bihari et al., 2024). Vegetation in both micro-regions was significantly altered by human activity by the Middle Ages, resulting in fragmented and variably degraded plant communities (Pifkó & Barina, 2004). According to the most recent CORINE Land Cover database, 73% of the municipality's administrative area is used as non-irrigated arable land, 7.7% is discontinuous urban fabric (~built-up areas), 6% is complex cultivation patterns, 5% is pasture, 2% is industrial and commercial area, 1.7% is covered by water bodies, and 1% is occupied by the airport. In addition, land uses such as orchards, recreational and sports facilities, forests, and shrublands each account for approximately 0.5–1% of the total area.

Mezőkövesd is the 4th most populous settlement in Borsod-Abaúj-Zemplén County, with a total population of 15,541 (as of January 1, 2024), covering an area of 100.49 km^2 and a population density of 162.3 inhabitants/km^2.

3. Materials and methods

To map the vegetation-covered areas of Mezőkövesd (hereinafter referred to simply as green spaces for simplicity), and to assess their condition, we used time-series satellite imagery. The satellite image analysis was carried out for the vegetation periods between 2017 and 2024, defined as March 1 to October 31 each year.

As the first step of the analysis, we used Google Earth Engine to automatically filter Sentinel-2 images with 10% cloud cover. From the datasets meeting this cloud cover criterion, we generated Normalized Difference Vegetation Index (NDVI) maps

$$NDVI_{t1} = \frac{NIR - RED}{NIR + RED} \tag{1}$$

This index is used to estimate photosynthetic activity and chlorophyll content in plants, as vegetation strongly reflects near-infrared (NIR) light and absorbs visible red (RED) light. NDVI values can be used to infer plant health, biomass quantity, and vegetation fertility—thus serving as an indicator of vegetation condition and density.

Based on the NDVI datasets calculated from satellite images taken at specific dates, we computed the average NDVI value for the vegetation period of each examined year

$$NDVI_{annual\ average} = \frac{1}{n}\sum_{i=1}^{n} NDVI_i \quad (2)$$

In addition, within the ArcGIS Pro software environment, we prepared the average NDVI map for the eight-year vegetation period (Figure 1/A). Furthermore, using the built-in Zonal Statistics tool in ArcGIS Pro, we calculated the standard deviation of the mean values for the examined years.

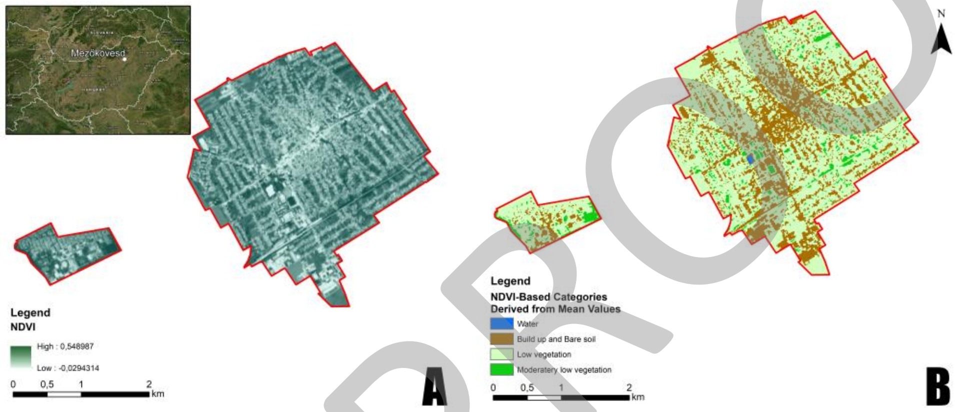


Figure 1
Spatial distribution of mean NDVI values (A) and vegetation categories classified based on those values (B)

As the second step, we calculated the Green Space Intensity Index (ZFI), developed by Jombach (2014). It is perfectly suitable for examining the condition, extent, and temporal changes of green spaces. Although the ZFI is based on the reclassification of NDVI values (Figure 2), it provides a much more intuitive and comprehensible representation of green space coverage than NDVI alone.

ZFI values range between 0 and 100, depending on the NDVI value of the given image element (pixel) (Jombach, 2014). The NDVI maps calculated for each year's vegetation period, as well as the average NDVI map for the entire study period, were reclassified in the ArcGIS Pro software environment to drive the ZFI values according to the method defined by Jombach (2014).

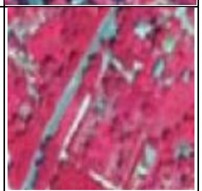
ZFI (%)	NDVI	Nature of the area	Sample
0 %	(-1)-0	Built-up area, paved surface, mining area, bare soil surface, and any area without biologically active green cover.	
0.01-19.99%	0-0.1	E.g., heavily built-up areas with very low green cover ratio.	
20-39.99%	0.1-0.2	E.g., built-up area with low green cover ratio (densely built suburban area, residential park-like development).	
40-59.99%	0.2-0.3	E.g., medium built-up area with medium green cover ratio (suburban areas).	
60-79.99%	0.3-0.4	E.g., relatively low built-up area with relatively high green cover ratio (housing estate development with large parks).	
80-99.99%	0.4-0.5	E.g., area characterized by low built-up density with a very high proportion of dense vegetation cover (gardens, parks, significant roadside green spaces).	
100%	0.5-1	Healthy forest stand, park with continuous woody vegetation and grass, vigorous lush grassland.	

Figure 2

Calculation method of the Green Space Intensity Index (ZFI) based on Jombach (2014)

As the third step of our research, we used the ZFI map generated from the 8-year average NDVI values and the population data from the Hungarian Central Statistical Office (KSH) for the calculation of green space per capita.

In addition to the above analyses, major green areas (parks, playgrounds, and public cemeteries) within the built-up area were identified through field surveys, digitized based on satellite imagery, and their pedestrian accessibility was evaluated.

Using the Network Analyst module of ArcGIS Pro, we created isochrone maps to visualize the accessibility of these different types of green spaces within the city, with varying temporal resolution. The workflow of the research methodology can be seen in Figure 3.

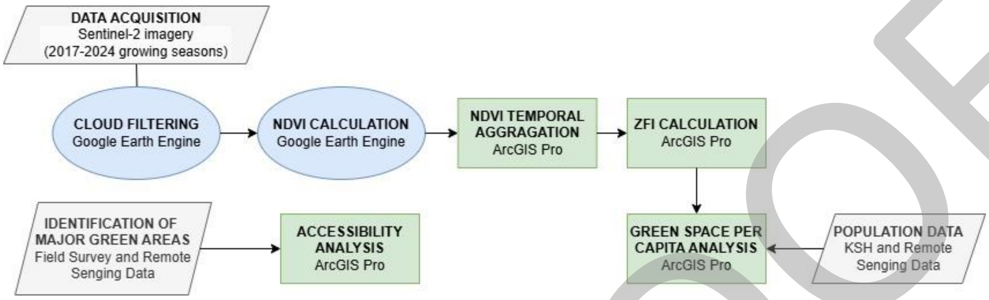


Figure 3
Workflow of the research

4. RESULTS

4.1. NDVI

Based on the average NDVI values for the studied years, higher values (dark green) indicate healthier, denser vegetation – typically associated with continuous forest patches and tree rows—while lower values (light green) correspond to sparser vegetation or unvegetated areas. During reclassification, NDVI values (Figure 1/A) were divided into four categories based on relevant literature (Alex et al., 2017; Nascimento Aquino et al., 2018), as shown in Figure 1/B: water surfaces, built-up/bare areas, low-vegetation, and moderately low-vegetation zones. Their respective proportions are presented in Table 1.

Within the urban area, water surfaces account for the smallest share. The built-up class includes the town center as well as the large buildings of the Zsóry Spa recreational zone (e.g., hotels and the sanatorium area), and linear infrastructure. These areas make up 27.8% of the built-up area (only 3.5% of the total administrative area). The low-vegetation category primarily includes the densely built-up suburban residential zones surrounding the city center and represents the largest share (66.9%). The moderately low-vegetation class includes primarily wooded or forested patches along the railway line and within the Zsóry Spa area, accounting for approximately 5% (Table 1).

Table 1

The area and percentage share of the territories classified into each category

	Administrative area (ha)		**Build up area (ha)**	
Water	71.24	0.71%	0.81	0.09%
Build-up and bare soil	355.03	3.53%	254.37	27.77%
Low vegetation	9082.37	90.38%	613.09	66.93%
Moderately low vegetation	540.09	5.37%	47.73	5.21%

Examining the standard deviation of NDVI values (Figure 4), it can be observed that areas characterized by persistently low NDVI values and minimal temporal variability – primarily the city center and the main transport corridors connecting the town to the surrounding settlements - represent priority zones for targeted green infrastructure interventions. The stability and consistently low vegetation activity in these areas indicate a dominance of impervious or intensively managed surfaces, where ecological functions are limited.

The implementation of tree planting initiatives and the expansion of urban green spaces in these zones could significantly improve the local microclimate by reducing the urban heat island effect, enhancing evapotranspiration, and providing shading. In addition, increasing vegetation cover would contribute to biodiversity conservation by creating new habitats and ecological corridors, while also supporting carbon sequestration and reducing atmospheric carbon dioxide concentrations. Furthermore, such interventions could improve air quality, mitigate surface runoff during extreme precipitation events, and enhance the overall environmental resilience and livability of the urban environment.

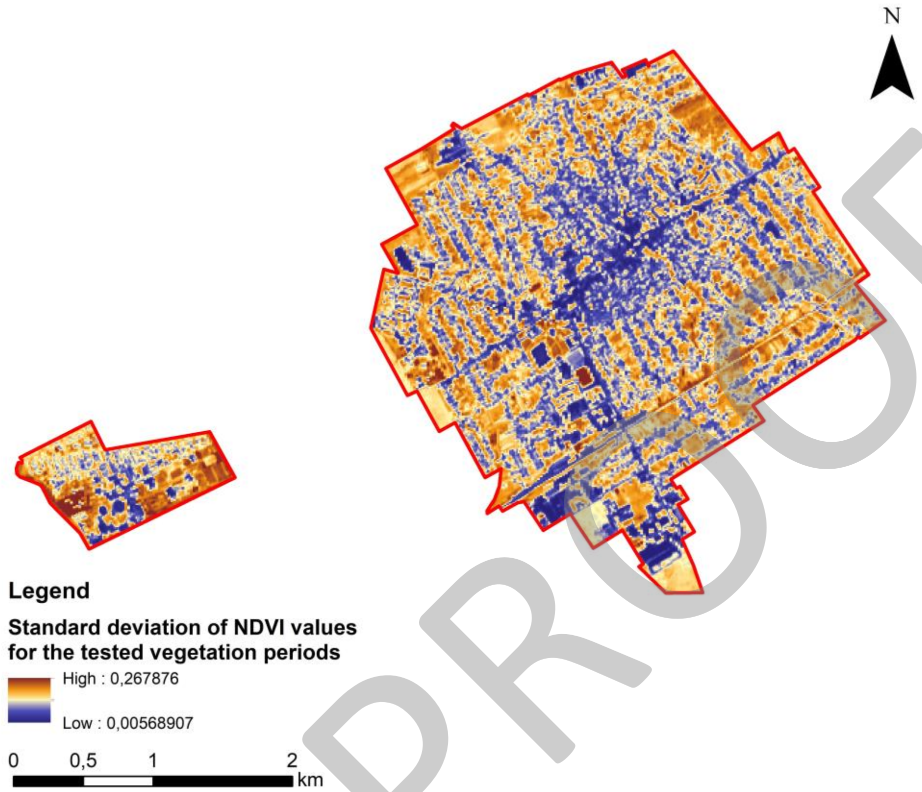


Figure 4
The standard deviation of NDVI values during the studied period from 2017 to 2024

4.2. ZFI

The extent of areas characterized by low building density and covered by a high proportion of dense vegetation (ZFI 80-99%), as well as areas characterized by healthy forest stands and continuous woody vegetation and grassland (ZFI: 100%), remained nearly constant (~±7%) during this period (Figure 4). A drastic change can be observed starting from 2022, when the two aforementioned categories completely disappeared (Figure 5). This change is not primarily due to an increase in built-up areas, but rather to drought conditions that have increased the costs of maintaining green spaces. Rising irrigation expenses place an increasing burden on residents and local authorities. According to HungaroMET data, precipitation was minimal at the beginning of the year, and only scattered showers alleviated the drought from April to mid-August, while heatwaves increasingly worsened the situation. The time series analysis also highlights that this trend had been ongoing in previous years, and as a result, the vegetation was unable to regenerate naturally and adequately. Owing to global climate change, the Carpathian–Pannonian region increasingly experiences extreme weather events (e.g., drought or, conversely, excessive rainfall). Given this trend, it is advisable to plant native or non-native tree species in the city's parks in the near future that can tolerate drought and extreme conditions well.

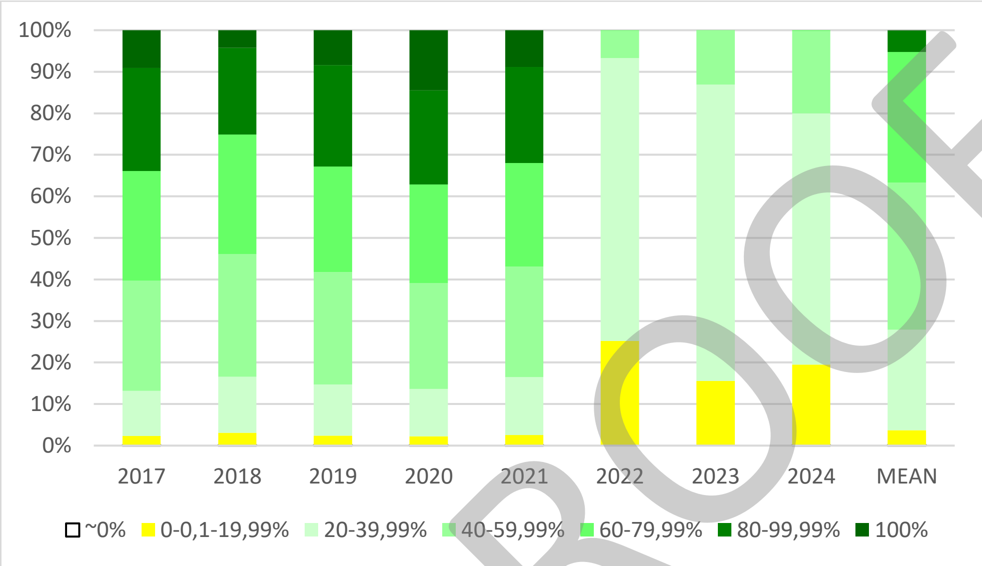


Figure 5
Change of the Green Surface Intensity Index (ZFI) in the inner area of Mezőkövesd (2017 – 2024)

4.3. Analysis of green space per capita

Due to significant changes in the condition of green spaces over the past three years caused by weather conditions, we used the ZFI map generated from the 8-year average NDVI values for further analyses (Figure 6). For the calculation of green space per capita, only areas with a ZFI value greater than 80% were considered. Based on the 2023 population data from the Hungarian Central Statistical Office (KSH) and the aforementioned criteria, the green space per capita within the inner urban area is 30.71 m^2, while within the entire administrative area it is 347.52 m^2. The value within the inner urban area exceeds the minimum recommended by the World Health Organization (WHO) (Russo & Cirella 2018), which is 9 m^2, but falls short of the ideal value suggested by the organization, which is 50 m^2.

Figure 6
Zonal Green Space Intensity Index (ZFI) map generated from the 8-year average NDVI values

The urban area was divided into five sections based on the main roads. The population of each district was estimated by considering the number and type of properties located within the area. Subsequently, using the estimated population and the area of zones with a ZFI value above 80% in each district, we calculated the amount of green space per capita. According to the results, the Mezőkövesd-Zsóry area has the highest per capita green space, while the district number 2 has the lowest value, which falls just slightly below the minimum recommendation set by the WHO (Table 2).

Table 2
Estimated and calculated data of the individual city districts

	Estimated Population (persons)	**Area with ZFI above 80% (m^2)**	**ZFI per Capita (m^2)**
Mezőkövesd-Zsóry	300	114 200	**380.6667**
Mezőkövesd-1	3295	128 000	38.8467
Mezőkövesd-2	2272	20 100	**8.8468**
Mezőkövesd-3	4356	73 900	16.9651
Mezőkövesd-4	6150	141 100	22.9430

4.4. Distance from major green areas

Based on the recommendation of the World Health Organization, major green areas should be accessible within a minimum of 15 minutes of walking. Assuming an average walking speed of 4-5 km/h, this condition is practically met from almost the entire area of the city along the roads.

When examining the accessibility of public parks, which are most suitable for recreational purposes (see Figure 7, top right panel), the situation is similarly favorable — only from the eastern and western edges of the city (about 8% of the total area) does it take more than 15 minutes to reach them.

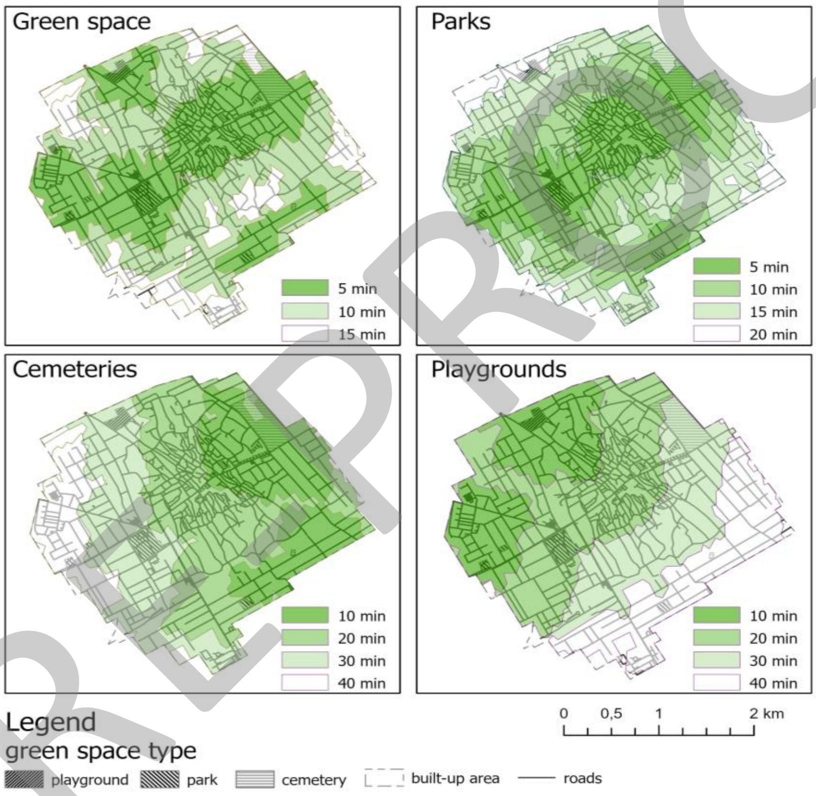


Figure 7
Green areas' pedestrian accessibility in minutes

If we consider cemeteries visited by elderly people or playgrounds that are primarily important for families with small children, a slower walking speed was assumed, and a 10-minute accessibility time was used as the basis. It can be established that neither cemeteries nor playgrounds located outside parks are reachable within 10 minutes from about three-quarters of the city. This is because these public areas are situated on the outskirts of the city. The cemeteries are located on the eastern side of the settlement, while playgrounds outside parks are on the western side.

For areas where the WHO criteria are not met, it is advisable to establish new recreational public spaces (parks, playgrounds) in the near future.

5. Conclusions

Our study examining the green areas of Mezőkövesd highlighted that using NDVI calculated from Sentinel-2 satellite images and the resulting Green Surface Intensity (ZFI) index is an effective method for spatial mapping and temporal analysis of vegetation-covered areas. The results show a positive trend in the condition of green spaces within the administrative boundaries between 2017 and 2021. However, due to the severe drought conditions starting in 2022, there was a drastic decline in vegetation health, especially in areas covered by natural vegetation. This underscores the local impacts of global climate change and the vulnerability of urban green infrastructure.

The amount of green area per capita within the built-up area exceeds the minimum recommended by the WHO but does not reach the ideal value, while some districts fall short of the desired green space availability. Accessibility to green spaces as recreational public areas is also uneven, making targeted greening interventions advisable in under-served neighbourhoods. Additionally, to improve climate resilience, it is recommended to plant drought-tolerant tree species in the city's green spaces that can better withstand climatic extremes.

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