HUNGARIAN UNIVERSITY OF AGRICULTURE AND LIFE SCIENCES

THE Ph.D. DISSERTATION

Urban Green Space Equity and Livability in Budapest, Erbil and Sulaimaniyah

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Budapest

2026

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1 BACKGROUND AND CONTEXTS

Since the dawn of civilization, nature has been essential, providing water, food, and shelter. Early settlements were closely tied to natural landscapes, with communities near mountains, forests, and water bodies. Agriculture enabled permanent settlements and shaped human societies (Redman, 1999). Civilizations such as the Sumerians, Greeks, and Romans integrated nature into urban life for functional and symbolic purposes, exemplified by the Hanging Gardens of Babylon (6th century BCE) (Wiseman, 1983). In the Middle Ages (5th-15th centuries), enclosed gardens in monasteries and castles served religious and practical purposes, while Islamic urban design introduced the 'paradise garden' and Charbagh concepts, emphasizing harmony of nature, water, and architecture (Lehrman, 1980). The Renaissance (14th-17th centuries) brought grand European gardens like Versailles by André Le Nôtre. Industrialization (18th-19th centuries) caused rapid urbanization and poor living conditions, prompting urban parks such as New York City's Central Park, designed by Frederick Law Olmsted to integrate nature, recreation, and social interaction (Eisenman, 2013). In the 20th and 21st centuries, figures such as John Muir, Ian McHarg, Jane Jacobs, Patrick Geddes, William Whyte, Ebenezer Howard, and Julius Gy Fábos shaped modern green space planning. They emphasized conservation, ecological planning, community-driven design, regional planning, public space, and greenways, promoting sustainable and livable cities (Duke, 2016; Yang and Li, 2016; Rosenberg, 1994; Mercer, 2003; Marcus and Francis, 1997; Culpin and Ward, 2015; Ryan et al., 2002).

This study focuses on Erbil and Sulaimaniyah, the largest cities in the Kurdistan Region of Iraq (KRI), experiencing rapid expansion in semi-arid climates, where residential growth often outpaces green space provision. Budapest serves as a European benchmark due to its comparable scale, population, and ring-and-radial layout, providing lessons for improving spatial equity and livability.

Global urbanization intensifies pressures on green spaces. By 2050, the world population is projected to reach 9.8 billion, with urban populations rising to 68% globally, 86% in developed countries, and 64% in developing countries (United Nations, 2012, 2017). Climate change poses additional risks, particularly in Iraq, where temperatures could rise by 4 °C by 2050 without intervention (Abdaki et al., 2021). Political instability, conflicts, and population displacement-such as the ISIS war (2014-2018), have further strained urban infrastructure in Erbil and Sulaimaniyah (Almukhtar, 2016; Khedir, 2021). Weak planning, rapid growth, and underinvestment in green spaces have led to fragmentation, inequitable access, and low per capita provision, highlighting the need for evidence-based strategies to support livable, sustainable cities (Wahab, 2023).

2 AIMS AND QUESTIONS

2.1 Goals and Objectives

This study aims to evaluate urban equity and livability through the lens of Urban Green Spaces (UGS), focusing on key indicators such as UGS ratio, per capita provision, proximity, and accessibility. The research examines the cities of Erbil and Sulaymaniyah in Kurdistan-Iraq and Budapest in Hungary, while situating the analysis within a broader global context of developed and developing countries.

The specific objectives of the study are as follows:

a) To synthesize the global development of Urban Green Spaces (UGS).

This objective explores the historical evolution, roles, and characteristics of UGS from their origins to the present, highlighting differences between developed and developing countries.

b) To examine the evolution and conceptual foundations of UGS equity assessment.

This includes identifying key theoretical frameworks, indicators, and tools used in assessing UGS equity, as well as understanding the relationship between distributional equity and spatial justice in urban planning.

c) To analyze trends in UGS ratio across Budapest and its districts.

The study investigates spatial and temporal changes in UGS ratio over the past three decades, identifying patterns of expansion, reduction, and land-use transformation across districts.

d) To assess the availability of UGS in relation to demographic change.

This objective evaluates the evolution of Urban Green Space per Capita (UGSPC) and its relationship with population density at city, district, and zone levels.

e) To compare UGSPC with international standards and planning policies.

The study assesses how well cities meet benchmarks such as WHO standards and examines alignment with local planning policies, identifying high-performing districts as potential benchmarks.

f) To analyze the impact of UGS elements on Land Surface Temperature (LST).

Using satellite imagery and ENVI-met simulations, this objective examines how different UGS elements (e.g., trees, lawns) and surface types influence LST and urban thermal conditions.

g) To evaluate UGS proximity based on spatial distribution.

This involves analyzing catchment areas using 300 m and 500 m buffer distances and comparing how different types of green spaces influence proximity.

h) To develop a practical approach for measuring UGS accessibility.

The study evaluates current methods and applies network-based tools (e.g., QGIS, OpenRouteService, real time Google Maps) to measure walking and car accessibility to UGS within defined time thresholds.

i) To develop a multi-criteria framework for assessing UGS equity and livability.

Using Multi-Criteria Decision Analysis (MCDA) and the Analytic Hierarchy Process (AHP), this objective integrates multiple spatial indicators to evaluate district-level performance and support sustainable urban planning decisions.

3 MATERIALS AND METHODS

3.1 Study Area Selection

This study employs a comparative spatial analysis of three cities: Budapest (Hungary), Erbil, and Sulaimaniyah (Kurdistan Region of Iraq).

3.2 Data Collection

A mixed-methods data integration approach was utilized, combining primary geospatial data with secondary demographic and meteorological datasets:

- **Geospatial & Satellite Imagery:** Copernicus CORINE Land Cover (CLC) and Urban Atlas (2018) were used for Budapest. Landsat 4-9 and Sentinel-2 L2A imagery (processed via Google Earth Engine) provided time-series data (1990–2024) for all cities.
- **Demographic Data:** Eurostat/Hungarian Central Statistical Office data were used for Budapest; LandScan-HD (90 m resolution) and local municipal census data were utilized for Erbil and Sulaimaniyah.
- **Supplementary Data:** OpenStreetMap (OSM) and Google Maps provided road and pedestrian network layers. Field surveys and local meteorological stations supplied microclimate baseline data and tree geometry for environmental modeling.

3.3 Analytical Framework

The methodology is organized into six primary workflows: Systematic Review, Spatio-Temporal UGS Analysis, UGS per Capita, Accessibility Modeling, Microclimate Simulation, and Multi-Criteria Decision Analysis.

3.3.1 Systematic Review

Following a PRISMA-guided systematic review of UGS Per Capita (UGSPC) literature.

3.3.2 Spatio-Temporal UGS Analysis

Spatial and temporal change of UGS were analyzed using Corine land cover and Urban atlas.

3.3.3 UGSPC analysis

Distributions of UGSPC were quantified using QGIS and Google Earth Engine (GEE). For Erbil and Sulaimaniyah, the Normalized Difference Vegetation Index (NDVI) was calculated to isolate green spaces (NDVI ≥ 0.2) during peak vegetation months.

3.3.4 Accessibility and Proximity Modeling

Accessibility was evaluated across three dimensions using QGIS:

- **Proximity Buffers:** Fixed-distance buffers (300 m and 500 m) were applied around UGS polygons to calculate the served population within intersecting grid cells.
- **Walking Accessibility:** Network-based walkability was assessed using the QNEAT3 plugin alongside OSM road networks, generating 5, 10, and 15-minute isochrones (approximating 400 m, 800 m, and 1,200 m).

- **Car Accessibility:** Initial driving isochrones (5, 10 and 15 minutes) were generated using the OpenRouteService (ORS) plugin. Since ORS consistently overestimated accessibility, the results were ground-truthed and empirically calibrated against real-time Google Maps travel data. Consequently, a correction factor of 0.8 was applied to adjust the spatial boundaries and better reflect realistic urban traffic conditions.

3.3.5 Land Surface Temperature (LST) and Microclimate Modeling

LST was retrieved utilizing a single-channel algorithm in GEE from Landsat Thermal bands (ST-B10). Brightness Temperature (BT) and the Proportion of Vegetation were used to calculate Land Surface Emissivity, ultimately converting the outputs to degrees Celsius.

To study localized microclimates (e.g., II. János Pál Pápa tér in Budapest), satellite-derived LST was compared against a 2.5D microclimate simulation built in ENVI-met 5. The agreement between the satellite observations and ENVI-met simulations was evaluated using a linear regression model:

3.3.6 Multi-Criteria Decision Analysis (MCDA)

Finally, to evaluate equity and livability among city districts, an Analytic Hierarchy Process (AHP) was applied. Using enhanced Saaty scale based on 1-5 Likert scale, the MCDA weighted multiple indicators including UGS ratio, NDVI, UGSPC, proximity (300 m and 500m distance buffer) and walking accessibility (5, 10 and 15 min).

4 NEW SCIENTIFIC RESULTS

The research findings are summarized in the following fifteen theses:

4.1 Title: Global disparities in Urban Green Space Per Capita (UGSPC)

Thesis 1: I have determined a global disparity in UGSPC, with developed-country cities showing higher median values than developing-country cities (43 m² vs. 6 m²) and fewer falling below the WHO minimum standard of 9 m² per capita (13% vs. 67%).

Explanation: A systematic review was conducted across the Scopus and PubMed databases using PRISMA. More than 1,400 articles were screened, more than 300 were fully reviewed, and 80 empirical studies met the inclusion criteria. These studies were analyzed to identify the UGS provision across all cities reported in the included papers. The cities were classified as belonging to developed or developing countries based on standard classification criteria[1]. The results show median UGSPC in cities of developed countries was 43 m², with a wide range from 2.5 to 126 m². However, the median UGSPC in cities of developing countries was 6 m², with a very wide range from 0.5 to 219 m. Even in developing countries, some cities can experience extremely high UGSPC (e.g., Dnipro, Ukraine, and Gandhinagar, India) thanks to their natural surroundings.

The analysis indicated adequacy relative to WHO standards for UGSPC (minimum of 9 m² and an ideal of 50 m²). In developed countries, a few (13%) did not reach the minimum, 38% exceeded the ideal level, and approximately half (50%) were between the minimum and ideal standards. In contrast, in developing countries, the majority (67%) of the cases did not reach the minimum level, only 9% exceeded the ideal level, and nearly a quarter (24%) were between these two thresholds. These suggest that urban planning in developing countries faces significant challenges in maintaining and expanding urban green spaces, particularly in the context of rapid population growth. The findings, therefore, highlight the need for stronger urban planning strategies to expand UGS in developing countries, while focusing on maintaining and enhancing UGSPC in developed countries.

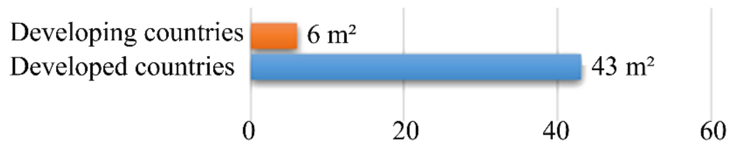


Figure 4.1 The median UGSPC in the cities of Developing and Developed countries (Source: the author) (Chapter 5.1.1)

[1] The International Monetary Fund (IMF)

4.2 Title: Spatiotemporal change in Budapest UGS Per Capita

Thesis 2: I determined that UGSPC in Budapest increased from 45 m² to 55 m² over three decades, representing a 22% increase partly as a result of population decline.

Explanation: As UGSPC is determined by the extent of UGS and population size, a spatiotemporal analysis of UGS was conducted using CORINE Land Cover data (1990 to 2018). The zonal histogram function is used for analysis. This dataset comprised four categories: Urban Green Areas, Sports and Leisure Facilities, Transitional Woodland and Shrubs, and Forests (including broad-leaved, coniferous, and mixed types). The total UGS areas were 8,917, 9,313, 9,320, 9,833, and 9,742 ha in 1990, 2000, 2006, 2012, and 2018, respectively, indicating an overall increase of approximately 9% during the study period, with a general increase at the beginning and a slight decrease of around 1% from 2012 to 2018.

Budapest **population data** were obtained from the Hungarian Central Statistical Office. The Excel data were joined to the spatial outputs via attribute tables. The population number **declined** from almost 2 million in 1990 to 1.7 million in 2020, representing a decrease of about 17%.

The results of that UGSPC in same period in Budapest were 44.5, 52.1, 53.2, 56.8, and 55.5 m^2. This shows continues increase with approximately 1 m^2 decrease after 2012. Overall, the results for Budapest over nearly three decades reveal a 22% increase in UGSPC, rising from 45 m² to 55 m². This increase was strongly influenced by both the expansion of UGS and population decline.

The results suggest that although UGSPC in Budapest increased over time, this improvement was largely driven by population decline rather than substantial expansion of UGS. Therefore, future planning should prioritize the protection and strategic enhancement of existing UGS rather than relying on demographic trends.

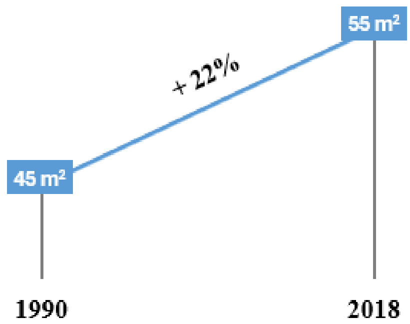


Figure 4.2 Urban Green Space Per Capita UGSPC increased by 22% from 1990 - 2018 based on CLC and Census data (Source: the author) (Subchapter 5.2.2)

4.3 Title: Spatial inequity of UGSPC in Budapest, Erbil, and Sulaimaniyah

Thesis 3: I justified the coexistence of high city-level UGSPC and low equity in Budapest, and contrasted this with Erbil and Sulaymaniyah, which exhibit low UGSPC and low equity.

Explanation: UGSPC and distribution **in Budapest** have been analyzed. UGS, based on the Urban Atlas datasets, included three groups: UGA, Sport and Leisure facilities, and Forests and Population data, which was based on census data. The city-level UGSPC **is 59 m², according to Urban Atlas, which is higher than the ideal level set by the WHO**. However, at the district level, fourteen **districts do not meet the 50 m² threshold** (the WHO ideal level). Moreover, **three districts have UGSPC values below the minimum threshold of 9 m²**. The district-based comparison used as indicator of low equity.

Meanwhile, the analyses of UGSPC have been conducted for both Erbil and Sulaimaniyah cities. UGS data were obtained from NDVI data from Sentinel 2, with a threshold of ≥ 0.2, defined as green space. The NDVI value was calculated as the mean NDVI of four years: 2021, 2022, 2023, and 2024, adjusted using municipalities' UGS data and spatial population data derived from LandScan-HD, which were then adjusted to match census data. The UGSPC **was 7 m² in Erbil** and **11 m² in Sulaymaniyah** at the city scale. Based on the WHO minimum standard of **9 m²** per capita, the results across the **inner, transitional, and outer zones** show a low-moderate-low (8, 10, and 5 m²) UGSPC pattern in Erbil, respectively, and a low-moderate-moderate (5, 13, and 14 m²) pattern in Sulaimaniyah.

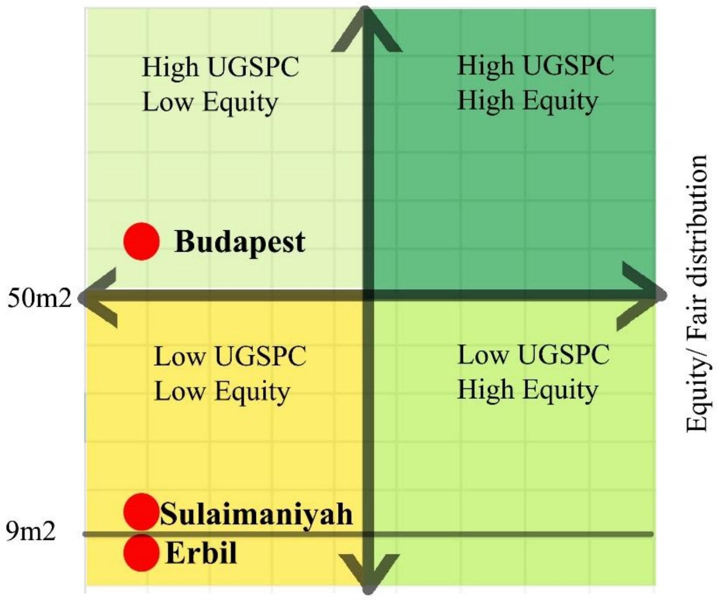


Figure 4.3 UGS Per Capita and Equity in Budapest, Erbil and Sulaimaniyah (Source: the author) (Subchapter 5.3)

4.4 Title: Low UGS proximity and low spatial equity

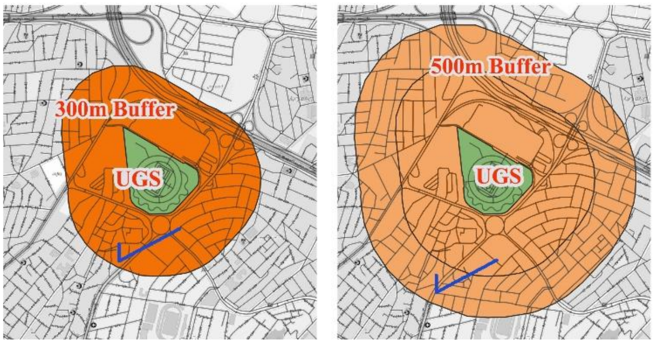
Thesis 4: I determined that UGS proximity in Budapest, Erbil, and Sulaymaniyah shows low value and high inequity, it is below the recommended level of the WHO standard, and the German standard.

Explanation: The study assessed how people live close to UGS and also compared the results with the WHO recommendation that residents have access to at least 0.5 ha of UGS within 300 meters, and the German standard, which recommends 500 meters. For Budapest, UGS data were derived from the Urban Atlas.

The results showed that **67% of Budapest's population meets this standard**. This proportion increased to **approximately 90% when the buffer distance was extended to 500 m**, which is still **lower than the recommended standard**. The high inequity of UGS proximity is observed when focusing on inner, traditional, and outer districts. **In the inner districts of Budapest,** accessibility to UGS within a 300 m buffer ranges from a **low 30% to a very high 95%. In the transitional** districts, accessibility ranges from **62% to 77%,** corresponding to a high level. **In the outer** districts, it is **moderate (43%) to very high (82%)**. **At the district level, ten districts have UGS proximity values below the citywide average of 67%**. However, at a distance of 500 m, this number was reduced to seven districts, despite increasing to the city average to 90%.

In Erbil and Sulaimaniyah, the UGS data were from municipal and adjusted with NDVI and orthophoto from Google Pro. The spatial results reveal that **only 16.4% of the population in Erbil and 15.8% of the total population in Sulaymaniyah live in areas that can reach UGS within 300m**. This shows a very low accessibility based on WHO. The people living within a **500m** buffer are also **very low, 30.9% and 30.6% in Erbil and Sulaimaniyah, respectively**. The results suggest that to meet the standards, planners need to increase the number of UGS and expand or join several existing small UGS, which are closer to the residents (less than 0.5 ha).

Budapest 67.0%
Erbil 16.4%
Sulaimaniyah 15.8%
of population live within
300m buffer of UGS



Budapest 90.0%
Erbil 30.9%,
Sulaimaniyah 30.6%
of population live within
500m buffer of UGS

Figure 4.4 Population proximity to UGS: 300m and 500m buffer zones in Budapest, Erbil, and Sulaimaniyah (Source: the author) (Subchapter 5.4.1)

4.5 Title: Variations in walking accessibility in Budapest, Erbil and Sulaimaniyah

Thesis 5: I determined that UGS walking accessibility varies across cities, reaching a near-universal level in Budapest (99% within 15 minutes) but remaining lower in Erbil (47%) and Sulaymaniyah (52%) for UGS areas larger than 0.5 ha.

Explanation: The UGS data were from the municipal and adjusted with both the four-year mean NDVI, during the peak season, utilizing Sentinel-2 imagery in Google Earth Engine and Google Earth Pro (0.5-1.5 m resolution), particularly when municipal data included both UGS and areas designated for UGS without actual creation. Orthophotos and field surveys were used to identify UGS gates and fences. For walking accessibility, the OSM Line road network is used. For 5, 10, and 15-minute walks. The network analysis used an ISO-area algorithm from the QNEAT3 plugin in QGIS. Gates and boundaries of unfenced UGS were used as targets to reach.

The results reveal that many citizens in Budapest, Erbil and Sulaimaniyah struggle to access UGS areas of over 0.5 ha on foot. In Budapest, it reached **37% of the population, in Erbil and Sulaimaniyah, it reached almost 90% at a 5-minute (400 m) threshold**. They are much below WHO standards. The proportion of the population without access decreased to **approximately 5% and 1% in Budapest on the 10- and 15-minute walking thresholds**, respectively. However, the corresponding **values remained high in Erbil (67% and 53%) and Sulaimaniyah (67% and 48%)**. The results show that at the first threshold, accessibility is low across the three cities, but reaching UGS by walking in **Budapest is much easier at the 10- and 15-min thresholds, almost meeting the universal standard of a 15-min city**.

The results suggest that urban planners in Erbil and Sulaimaniyah should improve the distribution of neighborhood-scale UGS to enhance walkable access. The high proportion of residents without access indicates poor pedestrian connectivity and unequal green-space distribution. In contrast, Budapest shows that a connected urban structure can better support 15-minute city principles and urban livability.

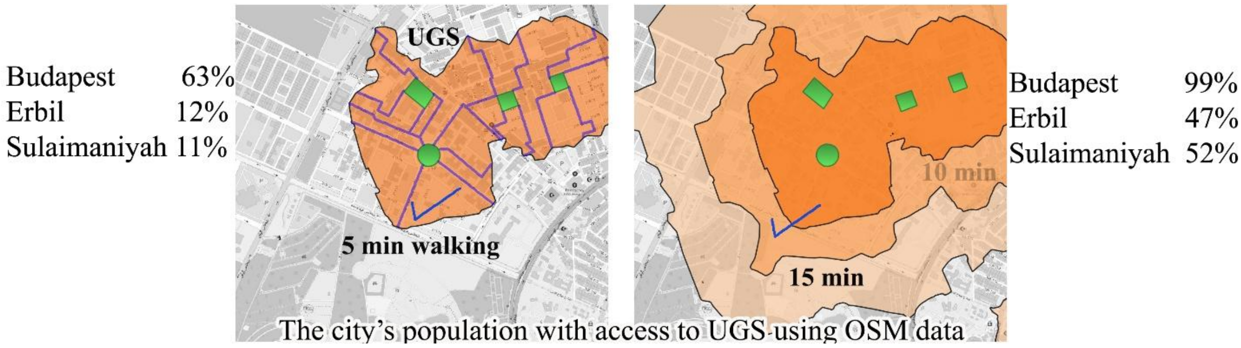


Figure 4.5 Population walking accessibility to UGS a comparison between Budapest, Erbil and Sulaimaniyah (Source: the author, Subchapter 5.4.2)

4.6 Title: Neighborhood parks dominate UGS proximity and walking accessibility.

Thesis 6: I have determined that Neighborhood parks provide the highest proximity and walking accessibility (near 80% and more) compared to other UGS types in Erbil and Sulaimaniyah.

Explanation: The analysis of UGS proximity with a 300m buffer revealed that the total values were only 16.4% of the total population in Erbil and 15.8% of the total population in Sulaimaniyah. From these, Neighborhood parks (0.5-5 ha) provide the highest level of access, covering 13.2% of the population in Erbil and 13.4% in Sulaimaniyah. In contrast, all other types, Community parks (5-10 ha), District parks (10-50 ha), and City parks (>50 ha), show less than 4% in Erbil and 3% in Sulaimaniyah. Even when the distance was extended to a 500m buffer, the total population within the buffer zone of UGS increased to approximately 31% for both cities. Neighborhood parks remain the highest and most dominant category, reaching 25.3% of the accessible population in Erbil and 26.2% in Sulaimaniyah.

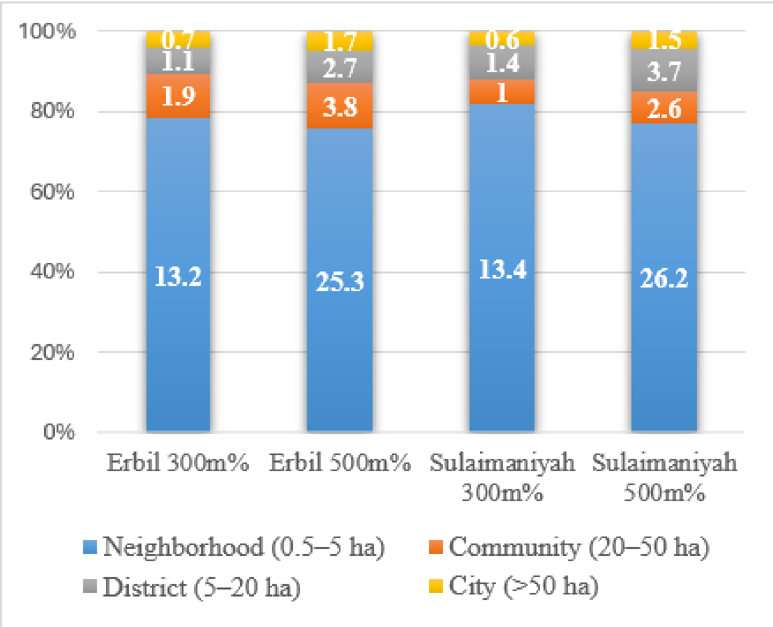


Figure 4.6 High Neighborhood parks accessibility based on a 500 m buffer in Erbil and Sulaimaniyah (Source: the author) (Subchapter 5.4.1)

Neighborhood parks consistently provide the highest walking accessibility to UGS in both Erbil and Sulaimaniyah. In Erbil, 12% of residents can reach any UGS within 5 minutes, and nearly all of this accessibility, almost 100%, is to Neighborhood parks. At 10 minutes, 33% of residents can access UGS, with 29% of Neighborhood parks, which represent more than 90%, and at 15 minutes, 47% can reach them, again with more than 90% corresponding to neighborhood parks. In Sulaimaniyah, the pattern is similar: 11% of residents can reach a green space within 5 minutes, nearly all being neighborhood parks; at 10 minutes, 33% can access green spaces, with 30% to neighborhood parks, which is more than 90%; and at 15 minutes, 52% can reach green spaces, with 47% specifically to neighborhood parks, which is also more than 90%. These results highlight that neighborhood parks are the main accessible green spaces for residents and underscore the need to protect and improve their quality and facilities.

Table 4.1 High Neighborhood parks accessibility based 5, 10, 15 min in Erbil and Sulaimaniyah (Source: the author) (Subchapter 5.4.2)

Erbil			**Sulaimaniyah**	
Total UGS accessibility	Neighborhood Park accessibility		Total accessibility to UGS	Neighborhood Park accessibility
12% (5 min)	12% (≈ 100%)		11% (5 min)	11% (≈ 100%)
33% (10 min)	29% (> 90%)		33% (10 min)	30% (> 90%)
47% (15 min)	45% (> 90%)		52% (15 min)	47% (> 90%)

4.7 Title: Spatial-demographic disparities in car accessibility to LUGS[2]

Thesis 7: I have justified that, although Erbil encompasses a larger served area across all travel thresholds, Sulaimaniyah captures a higher served population within 5-minute car trips, while Erbil serves more residents at 10- and 15-minute car travel times.

Explanation: The dissertation advances urban accessibility analysis for large UGSs by car through a novel method that integrates a calibrated approach with empirical data from Erbil and Sulaimaniyah. In the method, OpenRouteService (ORS) **travel-time estimates were first generated and then calibrated using real-time Google Maps data with a 0.8 correction factor, thereby justifying the car-based accessibility model against on-the-ground conditions**. This produces more realistic accessibility patterns for large urban green spaces (LUGS). The results reveal that broader spatial coverage does not necessarily translate into better population access.

Spatially, both cities show weak integration between LUGS and road networks. **In Sulaimaniyah, only 11% (48 km²), 24% (107 km²), and 38% (171 km²) of the urban area have accessibility within 5-, 10-, and 15-minute** drive times, respectively. **Erbil** performs better at longer thresholds, **reaching 14% (61 km²), 44% (188 km²), and 71% (305 km²).** However, these spatial patterns do not align with population access. Despite its lower spatial coverage, **Sulaimaniyah enables 37% of residents to reach LUGS within 5 minutes, compared to 31% in Erbil**. This advantage diminishes over time: **Erbil serves 74% and 95% of its population within 10 and 15 minutes, respectively, while Sulaimaniyah reaches 67% and 85%.**

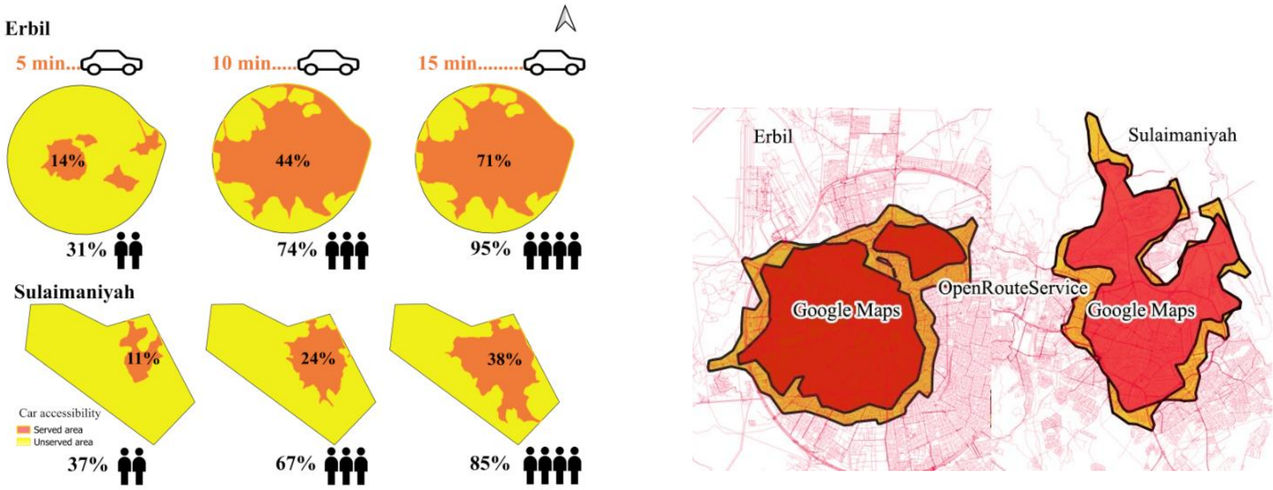


Figure 4.7 Area and population served in Erbil and Sulaimaniyah by car accessibility to LUGS based on a novel method (Source: the author) (Subchapter 5.4.1)

[2] LUGS: Large Urban Green Space

4.8 Title: Gates and distribution as a key driver of UGS car accessibility

Thesis 8: I justified that the spatial allocation of UGS and the number of operational gates have more effects on car accessibility than the overall size of the UGS in Erbil and Sulaimaniyah.

Explanation: The UGS sizes were classified based on the municipalities data. The accessibility was based on the enhanced methods of the OpenRouteService (ORS). In **Sulaimaniyah, Hawari Shar Park**, the **largest UGS in the study area with 582 ha, is in the outer zone** and has only **one active gate,** resulting in a **low car accessibility and the lowest served population percentages 61% of total population within 15 min threshold**. In contrast, **Azadi Park**, though significantly smaller at **49 ha,** is situated in a **high-density inner zone and has four active gates**, allowing it to **serve up to 83% of the city's population within 15 min car drive**. Similarly, in **Erbil, Hawar Park (17 ha**) with a **single gate** serves **52% of the population**, whereas the smaller **Aqua & Papwla Park (8 ha)**, with three gates and a central location, achieves higher coverage at **65%**. These cases illustrate that strong connectivity through multiple gates and strategic placement within dense urban areas can outweigh the disadvantage of smaller size.
The results indicate that planners need to increase the number of access points to LUGS and ensure these are well connected with the road network.

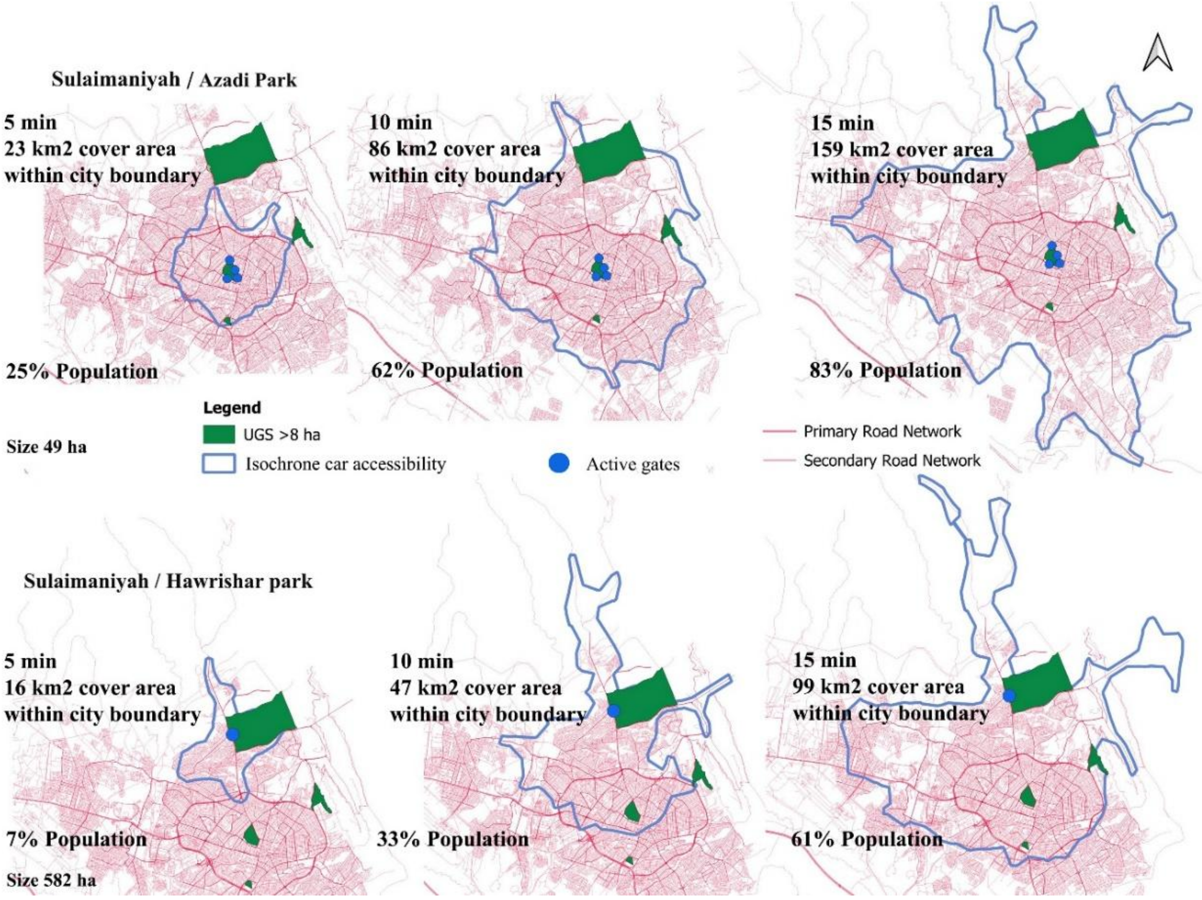


Figure 4.8 Comparison between Azadi Park and Hawarishar park and their performance in serving the population (Source the author) (Subchapter 5.4.3)

4.9 Title: Relation of tree cover with LST

Thesis 9: I demonstrated that tree cover with multilayer vegetation underneath has lower land surface temperatures (LST) than any other urban green space land-cover type.

Explanation: First, the method was tested in a pilot area in Törökbálint (Budapest agglomeration). Using Landsat 7, Landsat 9 and Sentinel-2 data from the vegetation period, we produced Green Space Intensity (GSI) maps (10 m, 30 m) for 2022 and Land Surface Temperature (LST) maps (30 m) for 2021-2022. **Results show a strong inverse relationship between vegetation and surface temperature: forests had the lowest LST (23-24 °C average), while industrial areas showed the highest (~34 °C)**.

In Sulaimaniyah, the seasonal changes of UGS and their effect on LST were analyzed. Using the Google Earth Engine (GEE) platform to process harmonized Landsat 8 and Landsat 9 generate seasonal median composites for the years 2023-2024. The land surface types were identified using high-resolution orthophotographs from Google Earth Pro. In the summer, when the city's temperature is too high, semi-natural forests and irrigated tree-covered areas exhibit the lowest surface temperatures. In some locations, **temperature differences of up to 5 °C were observed between forest zones and surrounding built-up areas.**

In applying an innovative method using Landsat 8 and ENVI-met to examine eight land surface types, given their significant influence on land surface temperature and, consequently, on urban temperatures, thermal comfort, and overall livability. The study was conducted in a Budapest urban park called 'II. János Pál Pápa tér' during the summer season. The LST results are based on Band 10 of Landsat 8 using the RS&GIS_V17.0 plugin in QGIS. The model was created using ENVI-met. The Regression analysis and RMSE showed a strong correlation between the two methods ($R^2 = 0.95$-0.98, $p < 0.01$), confirming the reliability of this approach**. The results reveal that a dense tree covered with shrubs underneath has the lowest surface temperatures, ~ 26 °C, as measured by Landsat and ~ 24 °C by ENVI-met** (as this measure was taken under the tree in this case).

All three studies suggest that urban planners should enhance livability in urban areas by improving thermal comfort through preserving forested zones, increasing tree planting, and implementing multilayered vegetation.

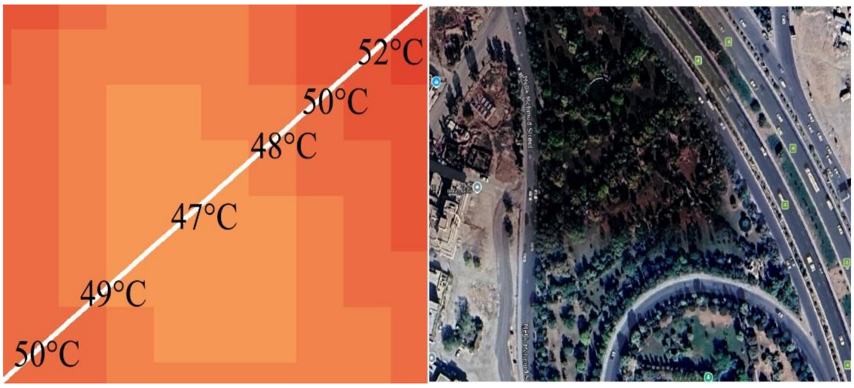


Figure 4.9 Lower temperatures in the tree-covered areas and higher surface temperatures on the roads and buildings at Wluba Roundabout Sulaimaniyah (Source: the author using google earth) (Subchapter 5.5)

4.10 Title: Ranking district-level equity and livability in Budapest

Thesis 10: I have determined UGS equity and livability at the district level in Budapest by applying a Multi-Criteria Decision Analysis model, with District Nr.1 demonstrating the best performance and District Nr 6 exhibiting the lowest performance.

Explanation: The analysis was to ensure a systematic evaluation of district performance using Multi-Criteria Decision Analysis (MCDA) framework, specifically employing the Analytic Hierarchy Process (AHP) with a simplified Saaty scale (1-5 scale) based on Likert scale. The model evaluated several criteria and sub criteria: **UGS ratio, NDVI, UGS Per Capita,UGS proximity (300 m and 500 m buffers) and UGS walkability (5, 10, 15 min).** After calculating the pairwise comparison matrix and normalizing the weights, the model was applied to the 23 districts of Budapest.

The results reveal a big difference in equity and livability across the city. **Notably, none of the 23 districts got a score high enough** to be classified as **'Very High'**. The north-west part of the city (North of Buda) and the south-east districts (South of Pest) are among the best districts. Several districts were close to that and reached **'High'** level, such as districts 1, 2, 3, 5, 9, 10, 12, 19 and 23 got 'High' scores, indicating relatively strong availability and accessibility of UGS in these areas. **From this group notability district 1 in the highest and 23 is in the lowest rank**. A large cluster of ten districts, including 4, 7, 8, 11, 13, 14, 18, 20, 21, and 22, were classified as **'Moderate'.** Districts 15, 16 and 17 were rated as the '**Low**' class, while **only districts 6** was in the '**Very low**' class.

The results highlight significant spatial inequality in UGS availability and distribution, indicating that planners should prioritize investment in low-performing districts to improve environmental equity and livability. For example, **District 8 has the lowest amount of UGS, yet it performs highly within the 800 m and 1200 m walking accessibility**. This indicates that although UGS is limited, residents can still access green spaces within reasonable travel distances; however, the green spaces are relatively small and dispersed. Therefore, planners should increase the number and size of UGS in this district. Notably, District 1 does not have the highest UGS ratio, NDVI, or UGSPC, but it achieved the highest overall performance due to its high proximity to UGS and strong road connectivity.

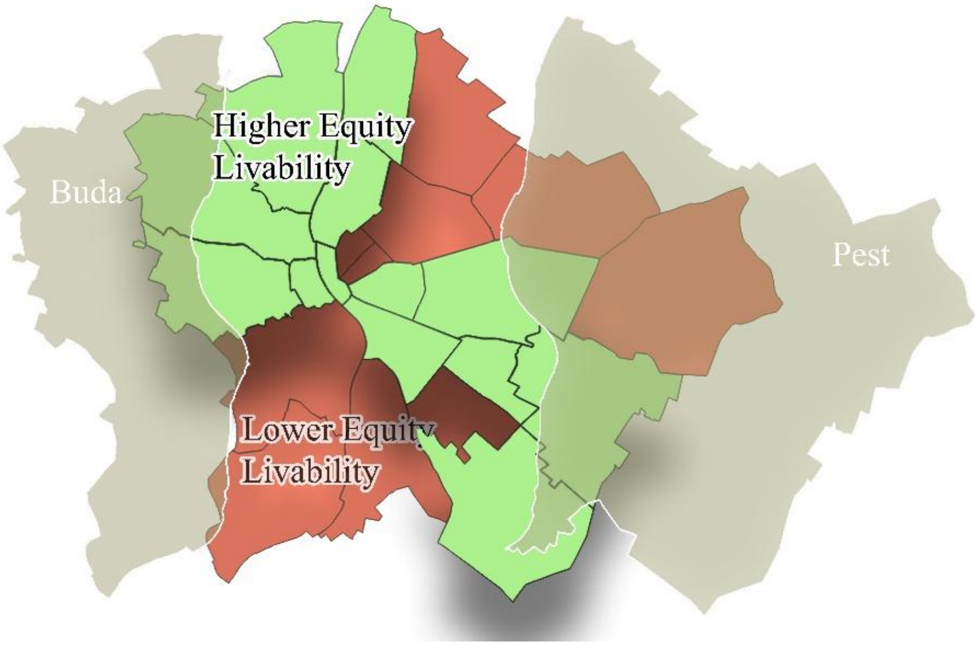


Figure 4.10 Overview of equity and livability in Budapest (Source: the author) (Subchapter 5.6)

5 CONCLUSION AND FUTURE DIRECTION

The dissertation concludes by summarizing the study's overall outline, revisiting the goals, structure, and outcomes of the dissertation, and highlighting key recommendations and directions for future studies.

5.1 Summary of the dissertation

This research examines the historical evolution, theoretical foundations, and empirical dimensions of UGS, emphasizing its role in shaping urban equity and livability. Through a combined theoretical and empirical approach, it provides a global synthesis of UGS development and evaluates disparities across both developed and developing contexts.

A systematic review reveals that UGS per capita (UGSPC) trajectories are highly context-dependent and non-linear, challenging conventional assumptions based solely on levels of development. The empirical component assesses equity and livability using multiple indicators, including spatial-temporal dynamics, distribution, proximity, accessibility, and environmental performance (e.g., Land Surface Temperature), supported by a Multi-Criteria Decision Analysis (MCDA) framework.

Key findings include:

- **Spatial-temporal dynamics:** In Budapest, UGS and UGSPC increased over three decades, driven by both spatial expansion and population decline, with changes influenced by vegetation growth and land management practices.
- **Provision (UGSPC):** Budapest exceeds recommended standards, while Erbil and Sulaimaniyah remain close to minimum thresholds, with intra-urban disparities at district levels.
- **Proximity and distribution:** Although Budapest performs comparatively better, all case cities fall below WHO and ANGSt benchmarks, with significant spatial inequities.
- **Walkability:** None of the cities meet WHO walkability standards (5-15 minutes), with neighborhood parks constituting the most accessible UGS type.
- **Accessibility (car-based):** Car accessibility to large UGS remains limited, covering only partial urban areas even within extended travel thresholds.
- **Environmental performance:** Vegetation, particularly tree cover, significantly reduces surface temperatures, highlighting the climatic importance of UGS quality.
- **Integrated assessment:** The MCDA (AHP-based) model provides a holistic evaluation by integrating spatial, ecological, and accessibility indicators.

Overall, the study advances understanding of UGS as a critical component of equitable and livable cities, offering practical insights for planners and policymakers and contributing to sustainable urban development goals.

5.2 Recommendation for future direction

Given the multidimensional nature of equity and livability, future research should adopt more integrated and data-driven approaches:

Socio-spatial differentiation: Incorporate socio-economic and demographic variables (e.g., age, income, mobility constraints) to better capture differentiated UGS needs and usage patterns.

Standardization and classification: Develop context-sensitive UGS classification frameworks and integrate them with future urban, demographic, and climate scenarios, particularly within the "greener and denser" paradigm.

Multimodal accessibility: Expand accessibility analysis to include public transport, cycling, and dynamic travel conditions, accounting for temporal and seasonal variability.

Advanced data and methods: Utilize emerging data sources (e.g., mobile location data) and computational techniques (e.g., AI, ANN, GA) to improve the accuracy of spatial equity assessments and support complex decision-making processes.

6 LIST OF PUBLICATIONS

No.	Authors, Title & Journal/Source	Year
1	**YN Hassan**, S Jombach — *Urban Green Space per Capita for Sustainable and Equitable Urban Planning: A Systematic Review and Bibliometric Analysis*, **Land 15 (1), 29**	2026
2	Kawar Salih, **YN Hassan**, Sándor Jombach, Ildikó Réka Báthoryné Nagy— *A Comparative Analysis of Land Surface Temperature (LST) Data from Landsat-8 and ENVI-met Monitoring Softwares: A Case Study of an Urban Park in Budapest,* **Ybl Journal of Built Environment 10 (1)**	2025
3	C Du, B Sölch, X Wang, **YN Hassan**, S Jombach — *Identifying Spatiotemporal Characteristics of Carbon Storage in Green Spaces of Newly Developed Residential Areas Using High-resolution Mapping*, **Journal of Digital Landscape Architecture (and Conference Presentation) 10, (366-376)**	2025
4	**YN Hassan**, HA Mohammed, M Abuhayya, S Jombach — *Assessing Travel-Time Accessibility to Urban Green Spaces in Car-Dependent Cities: Evidence from Erbil and Sulaimaniyah, Kurdistan Region of Iraq*, **Land 14 (9), 1886**	2025
5	S Jombach, **YN Hassan**, JR Wagner, C Du, B Sölch, L Üsztöke — *Changes in Green Space Intensity in Újbuda, in Budapest's 11th district*, **4D Tájépítészeti és Kertművészeti Folyóirat 74, (2-23) Journal of Landscape Architecture and Garden Art**	2024
6	ZF Ali, **YN Hassan**, G Pirisi, K Kiss, P Maleknia, N Ugwonoh — *Seismic Activity Hazard Assessment Using GIS Techniques in a Vulnerable Urban Area of the Iraq Kurdistan Region*, **Journal of Digital Landscape Architecture 9, (511-520) (and Conference Presentation)**	2024
7	**YN Hassan**, ZF Ali, L Üsztöke, S Jombach — *A Comparative Assessment of UGS Changes and Accessibility Using Per Capita Metrics: A Case Study of Budapest and Vienna*, **Digital Landscape Architecture 9, (723- 733) (and Conference Presentation)**	2024
8	S Jombach, L Üsztoke, **YN Hassan**, You Chenyu — *Green Space Intensity, Land Surface Temperature and Green Canopy Top Mapping: A Case Study in the Suburban Settlement of Törökbálint, Hungary*, **Journal of Digital Landscape Architecture 8, (417-426) (and Conference Presentation)**	2023
9	S Jombach, L Üsztöke, **YN Hassan** — *Changes in Green Space Intensity in Budapest's 14th district = Zöldfelület-intenzitás változásai Budapest XIV. kerületében*, **4D Tájépítészeti és Kertművészeti Folyóirat / Journal of Landscape Architecture and Garden Art 67, (30-43)**	2023
	Authors, Title & Conference	**Year**
10	**YN Hassan**, S Zhen, AOM Sharbazhery, C Du, S Jombach — *Evaluating Urban Green Space Accessibility and Per Capita Distribution in Erbil and Sulaymaniyah, Kurdistan Region of Iraq*, **Fábos Conference on Landscape and Greenway Planning 8 (1)**	2025
11	C Du, S Ge, X Wang, **YN Hassan**, S Jombach — *Assessing and Perceiving the Carbon Storage Potential of Urban Green Spaces to Improve Environmental Sustainability: A Case Study in Parks of Zhengzhou, China*, **Fábos Conference on Landscape and Greenway Planning 8 (1)**	2025
12	Kawar Salih, **YN Hassan**, Sándor Jombach, Ildikó Réka Báthoryné Nagy — *A Comparative Analysis of Land Surface Temperature (LST) Data from Landsat-8 and ENVI-MET Software: A Case Study of an Urban Park in Budapest,* **Ybl Conference on the Built Environment – Book of Abstracts 2, (12- 13)**	2024