NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

Bulletin of Geography. Socio-economic Series, No. 72 (2026): 125-139
http://doi.org/10.12775/bgss-2026-0019

BULLETIN OF GEOGRAPHY. SOCIO–ECONOMIC SERIES

journal homepages:
https://apcz.umk.pl/BGSS/index
https://www.bulletinofgeography.umk.pl/

Geospatial analysis of urban green space enjoyment in Mashhad metropolis based on Multi-Criterion Spatial Decision Support System (MC-SDSS)

Qadir Siaami[1, C], Sajedeh Baghban[2, DFPMR], Mina Jahan Tigh[3, DM]

[1,2,3]*Imam Reza International University,* Department of Urban Planning and Architecture, Mashhad, Iran, [1]e-mail: q.siaami@imamreza.ac.ir, [1]https://orcid.org/0000-0001-7069-8019; [2]e-mail: sbaghban@imamreza.ac.ir, [2]https://orcid.org/0000-0001-6660-9263; [3]e-mail: Jahantighmina6@gmail.com

How to cite:
Siaami, Q., Baghba, S., & Tigh, M.J. (2026). Geospatial analysis of urban green space enjoyment in Mashhad metropolis based on Multi-Criterion Spatial Decision Support System (MC-SDSS). *Bulletin of Geography. Socio-economic Series,* 72(72): 125-139. DOI: http://doi.org/10.12775/bgss-2026-0019

Abstract. This study conducts a spatial analysis of sustainable development in Mashhad, Iran's second-largest metropolis, focusing on urban green space (UGS) enjoyment. Utilizing a descriptive-analytical approach paired with the multi-criterion decision-making (MCDM) method, the assessment encompasses the city's 13 districts. Data analysis was performed using ArcMap software, categorizing the districts into five development levels: very developed, developed, relatively developed, deprived, and very deprived. The key statistical findings are as follows: The spatial analysis reveals a Moran's I index of 0.19, indicating a clustered distribution and spatial autocorrelation in the availability of green spaces across Mashhad's districts. Additionally, the analysis of the G statistic shows no significant local clustering or hot/coldspot patterns. To further understand the factors affecting green space availability, geographically weighted regression (GWR) was employed. The results reveal that ~60% of the variability in UGS enjoyment is accounted for by green space area and population growth rate, with coefficients of determination of 0.57 and 0.59, respectively.

Article details:
Received: 16 March 2025
Revised: 16 April 2026
Accepted: 22 May 2026

Key words:
geography,
planning & development,
urban green space,
sustainable development,
multi-criteria spatial decision support system,
Mashhad metropolis

Contents:

1. Introduction 126
2. Research materials and methods 127
   2.1. Field site 127
   2.2. The Multi-Criterion Spatial Decision Support System (MC-SDSS) framework 128
   2.3. Data collection, data processing and data analysis 129
3. Research results 131
   3.1. UGS enjoyment in Mashhad districts 131
   3.2. Analysis of the spatial pattern of UGS enjoyment in Mashhad metropolis districts 133
   3.3. Modeling factors affecting UGS enjoyment by GWR 133
   3.4. Synthesis of key findings 135
4. Discussion and conclusions 135
Note 137
References 137

1. Introduction

Rapid urbanization, particularly in the Global South, intensifies pressures on urban ecosystems and equitable service delivery, placing the sustainable development of cities at the forefront of geographical and planning inquiries (Kiamba, 2012; Cui, 2018; Carli et al., 2018; Awuah & Abdulai, 2022).

In Iran, recent changes in urban development have led to a shift away from traditional urban areas with modern urban designs, alongside significant alterations in various economic, social, environmental and physical factors (Pilehvar, 2021). These changes have adversely affected the efficiency of urban areas in meeting residents' needs. Given the complexity of urban systems, their conditions are not always straightforward or easily changeable. Therefore, a careful analysis from a sustainability perspective is essential to examine all relevant factors and identify key influences on urban development (Gonzalo et al., 2015; Correia & Roseland, 2022).

One of the defining characteristics of cities in the Global South is intense concentration and imbalance, where numerous assets and amenities are concentrated in one or a few neighborhoods, while others remain marginal (Smith, 2019). The evident disparity in development levels across various urban areas in Iran since the 1960s has led to widespread incompatibility within cities. This has created abnormal living conditions and imposed unequal distributions of resources and services, undermining social justice and challenging the pursuit of sustainable urban development (Pilehvar, 2021).

Improving and expanding green space as a vital urban asset can significantly reduce inequalities and enhance the quality of life for citizens (Jain, 2024). Green spaces are a strong defense against climate change and are critical in preserving urban ecosystems (Athokpam et al., 2024). Therefore, it is essential to monitor changes in the distribution of green space and promote its integration into sustainable urban development to create healthy and balanced cities in response to contemporary challenges (Halecki et al., 2023).

The importance of various types of green spaces, such as parks, gardens and green islands, in urban environments cannot be overstated; they are indicators of societal development and criteria for enhancing the quality of living spaces (Jain, 2024; Wheatley, 2024). Consequently, green space is a key factor in forming sustainable cities. Its most significant impact lies in its environmental function, which enhances the urban environment and mitigates the adverse effects of industrial expansion, thereby improving the biological quality of urban areas (Pirmoradian & Ashtari, 2020; Teimouri et al., 2023). However, rapid urbanization worldwide has disrupted the balance between urban land use and diminished green and natural spaces, particularly in developing countries (Ramaiah & Avtar, 2019).

The city of Mashhad, Iran's second-largest metropolis and a major pilgrimage destination, embodies these conflicts with acute specificity. It faces a critical spatial-demographic imbalance, with a high annual population growth rate (2.65%) vastly outstripping its physical expansion (0.17%), thereby intensifying pressure on all land resources, including UGS .While its reported *per capita* UGS (8 m²) meets the national minimum standard (7–12 m²), this average masks severe intra-city inequalities in access, quality and enjoyment – a core issue of spatial justice (Mashhad Municipality, 2007; Mashhad Municipality, 2022; Sabet Teimouri et al., 2022).

Therefore, the core geographical problem addressed in this study is not merely to quantify an average UGS inequality within Mashhad but to diagnose its spatial pattern and drivers. This research examines the distribution patterns of various types of urban green space (UGS) at the district level. Recognizing that UGS enjoyment is influenced not only by the area of green space but also by factors such as population density and accessibility, this study spatially analyzes the inequitable access to UGS in Mashhad to identify deprivation hotspots and inform equitable urban planning.

Urban green spaces play a crucial role in sustainable development and improving the quality of life in cities. They provide numerous environmental benefits, including ecosystem services, mitigation of urban environmental issues and enhancement of urban ecology (Kaur et al., 2021; Núñez, 2021; Li, 2023; Zhang & Qian, 2024). Green spaces contribute to human health and well-being and social cohesion, and – through increased property values and tourism – to economic development (Zhang & Qian, 2024). However, urban expansion and land pressure pose challenges to green space management (Li, 2023). Studies have shown that green space distribution is often inequitable, with public parks frequently located far from slum areas (Kaur et al., 2021). The spatial patterns of UGS can be quantified using landscape metrics and gradient analysis, revealing distinct characteristics for different types of green spaces (Zhang et al., 2019). The availability of UGS varies across European cities, with metropoles and large cities having more "urban green" and smaller cities having more "natural green" (Baycan et al., 2002). Comparative studies of European cities have revealed variations in UGS enjoyment and planning performance between southern and northern European cities (Baycan-Levent et al., 2009). These research efforts demonstrate the importance of comprehensive, multi-dimensional approaches in UGS analysis and planning to enhance urban sustainability and residents' well-being. The novelty of this study lies in generating a spatially-explicit diagnostic model that captures both the structural patterns and local drivers of UGS inequality in a context marked by rapid growth, limited natural greenery and unique seasonal pilgrimage pressures, thereby offering a transferable methodological approach for similar cities in the Global South.

To achieve sustainable urban development, it is essential to strengthen the planning, design and management of green spaces (Karade et al., 2017; Li, 2023). Urban planners and policymakers should prioritize the integration of green infrastructure in city development to create resilient and sustainable urban environments (Zhang & Qian, 2024). In the context of this study, sustainable development is interpreted through a spatial equity lens. We adopt the three-pillar model, encompassing environmental, social and economic sustainability (United Nations, 2015), with a particular focus on the social (equity) dimension. Specifically, we conceptualize sustainable urban development as a process that meets the environmental need for greenery and ecosystem services while ensuring just and equitable spatial distribution of these benefits across different urban communities. Thus, analyzing and rectifying the spatial disparities in UGS access is posited as a fundamental prerequisite for achieving true sustainability in Mashhad.

Geographic Information System (GIS) has been utilized to assess UGS and identify suitable locations for new green spaces (Mostafapour et al., 2015; Anteneh et al., 2023). Remote sensing techniques, like those using Sentinel-2 data, enable multi-scale assessments of urban green spaces, allowing for city comparisons and deficit analysis (Eichler et al., 2020).

Spatial analysis techniques are valuable for understanding the distribution and dynamics of UGS (Rahnama & Shaddel, 2019; Zhang et al., 2019). The application of MCDM methods like the Analytical Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) has proven effective in evaluating potential UGS sites (Reyes Escalante et al., 2020). These approaches integrate various factors such as accessibility, size and environmental benefits (Reyes Escalante et al., 2020; Anteneh et al., 2023).

Various indicators have been developed to assess and plan these spaces, focusing on availability, accessibility and distribution (Teimouri & Yigitcanlar, 2018; Campagnaro et al., 2019; Biernacka, 2020). Common indicators include *per capita* green space, distance-based accessibility, and balanced distribution (Teimouri & Yigitcanlar, 2018; Biernacka, 2020). More comprehensive analyses incorporate attractiveness factors such as cleanliness, equipment and biodiversity (Biernacka, 2020). Despite the importance of these indicators, their application in planning and management is often overlooked by policymakers (Campagnaro et al., 2019). Implementing these indicators can guide decision-making to enhance UGSs and meet international sustainability goals (Campagnaro et al., 2019; Biernacka, 2020).

The distinguishing feature of this research, in comparison to other studies, is its integrated and comprehensive approach to the field of green space. In this study, the assessment of green space within the context of sustainable development extends beyond mere *per capita* measurements and area considerations; it incorporates a multitude of criteria and variables into the analysis. Rather than simply ranking spatial distributions or examining related indicators, this research employs a multifaceted analysis that utilizes various indices, including Local Moran's I and Gi index, to investigate the distribution and dispersion of UGS. The application of these diverse indices not only reflects the quantitative aspects of UGS but also reveals insights into its qualitative spatial distribution, establishing a significant distinguishing factor for this research relative to others. Each analytical index uniquely highlights different characteristics of spatial distribution; thus, combining these indices yields a more nuanced and comprehensive understanding of the studied areas within the context of UGS. Moreover, the study employs Geographically Weighted Regression (GWR) to model the factors influencing changes, enabling a more precise analysis of the spatial and temporal relationships among variables. Consequently, this comprehensive and integrated approach has the potential to inform the development of more effective policies aimed at improving and promoting the sustainable development of UGS across cities, while also providing an accurate representation of the conditions and needs specific to each region.

2. Research materials and methods

2.1. Field site

Mashhad, the capital of Khorasan Razavi Province, is located in north-eastern Iran with geographical coordinates of 36.2605° N and 59.6168° E. The city is situated in the Kashafrud River basin and is surrounded by the Hezar-masjed and Binaloud mountain ranges, which significantly influence its local climate and water resources. Mashhad has a semi-arid climate characterized by hot, dry summers and cold winters, with low annual precipitation averaging around 250 mm (Mashhad Municipality, 2022). This climatic condition poses an inherent challenge for the development and maintenance of lush, water-intensive urban greenery, making the planning and equitable distribution of existing green spaces even more critical. With a population of over three million people, it is recognized as one of the largest and most populous cities in Iran (Fig. 1). Additionally, as a religious and tourist destination, Mashhad hosts nearly 30 million domestic and foreign pilgrims and tourists annually due to the presence of the Imam Reza (AS) shrine, placing exceptional and cyclical pressure on its urban infrastructure, including parks and public spaces. Mashhad covers ~351 square kilometers and is divided into 13 municipal districts, each with its own characteristics and needs (Sabet Teimouri et al., 2022). Broadly speaking, the urban green spaces (UGSs) in Mashhad consist primarily of public parks, neighborhood green patches, street plantations, and the historic gardens surrounding the holy shrine. Their spatial distribution is historically uneven, with a higher concentration in the central and southern districts developed during earlier planned phases, while newer northern and north-eastern expansions often exhibit lower green cover. The UGS in Mashhad is estimated to be ~8 square meters per person on average (Mashhad Municipality, 2022), which is significantly less than international standards (~20 m²) and is within the lower range of the national standards defined by MHUD (7–12 m²). This average, however, masks significant qualitative and accessibility differences, from well-maintained formal parks to neglected green patches. Figure 1 shows the location of the study area and the dispersion of UGSs in the city.

2.2. The Multi-Criterion Spatial Decision Support System (MC-SDSS) Framework

The core methodological framework of this study is a Multi-Criterion Spatial Decision Support System (MC-SDSS). An MC-SDSS integrates Geographic Information Systems (GIS) with Multi-Criterion Decision-Making (MCDM) methods to structure, evaluate and visualize complex spatial planning problems involving multiple, often conflicting, criteria (Santos et al., 2025). In this research, the MC-SDSS was implemented as Figure 2 through a sequential three-stage process to assess UGS enjoyment in Mashhad:

1. Problem Structuring & Input: The spatial problem (unequal UGS enjoyment) was defined, and relevant criteria (the nine indicators) and spatial units (the 13 districts) were identified. All data were georeferenced within a GIS environment.
2. Analysis & Processing: This stage combined MCDM and spatial statistics. The TOPSIS technique was applied to integrate the nine indicators and calculate a composite Closeness Index for each district, ranking them by overall UGS enjoy-

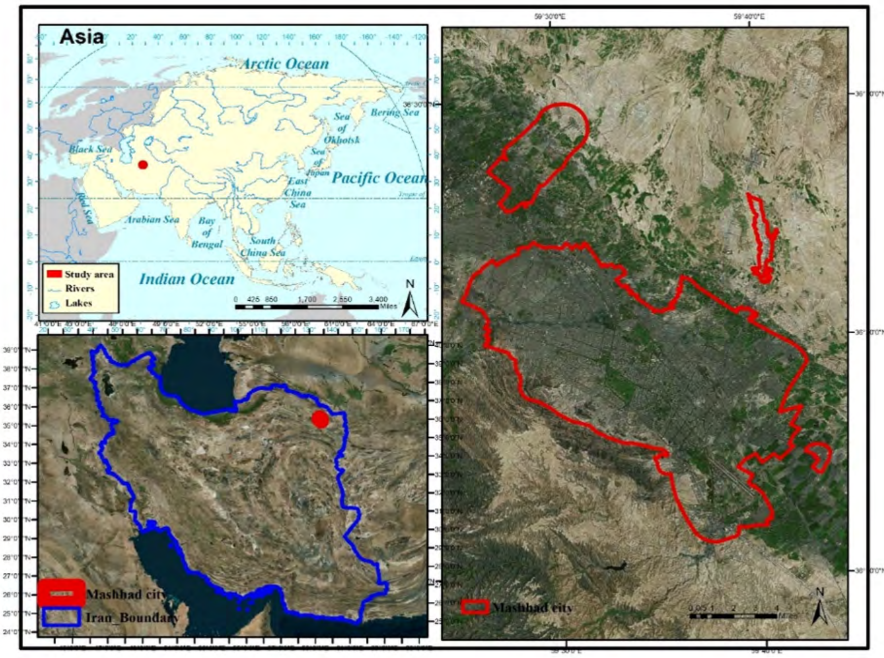

Fig. 1. Study area
Source: own elaboration

ment. Subsequently, spatial statistics (Global Moran's I and Getis-Ord Gi) were used to analyze the pattern and significance of the resulting spatial distribution. Finally, Geographically Weighted Regression (GWR) was employed to model local relationships between key drivers and the enjoyment score.

3. Output & Synthesis: The outputs, including district classification maps, spatial autocorrelation results and local coefficient maps from GWR, were synthesized to provide a comprehensive spatial diagnosis for planning support. Thus, the MC-SDSS served as the overarching analytical engine that connected raw spatial data to actionable policy insights.

2.3. Data collection, data processing and data analysis

This research employs a descriptive-quantitative and analytical approach, focusing on the 13 districts of Mashhad as the statistical population. The necessary data were gathered from the Parks and Green Space Organization of Mashhad Municipality and the National Statistics Portal for the year 2023. To assess Urban Green Space (UGS) enjoyment comprehensively, nine indicators were selected and operationalized. The selection rationale was based on capturing the three core dimensions of UGS sustainability: (1) Supply & Environmental Function

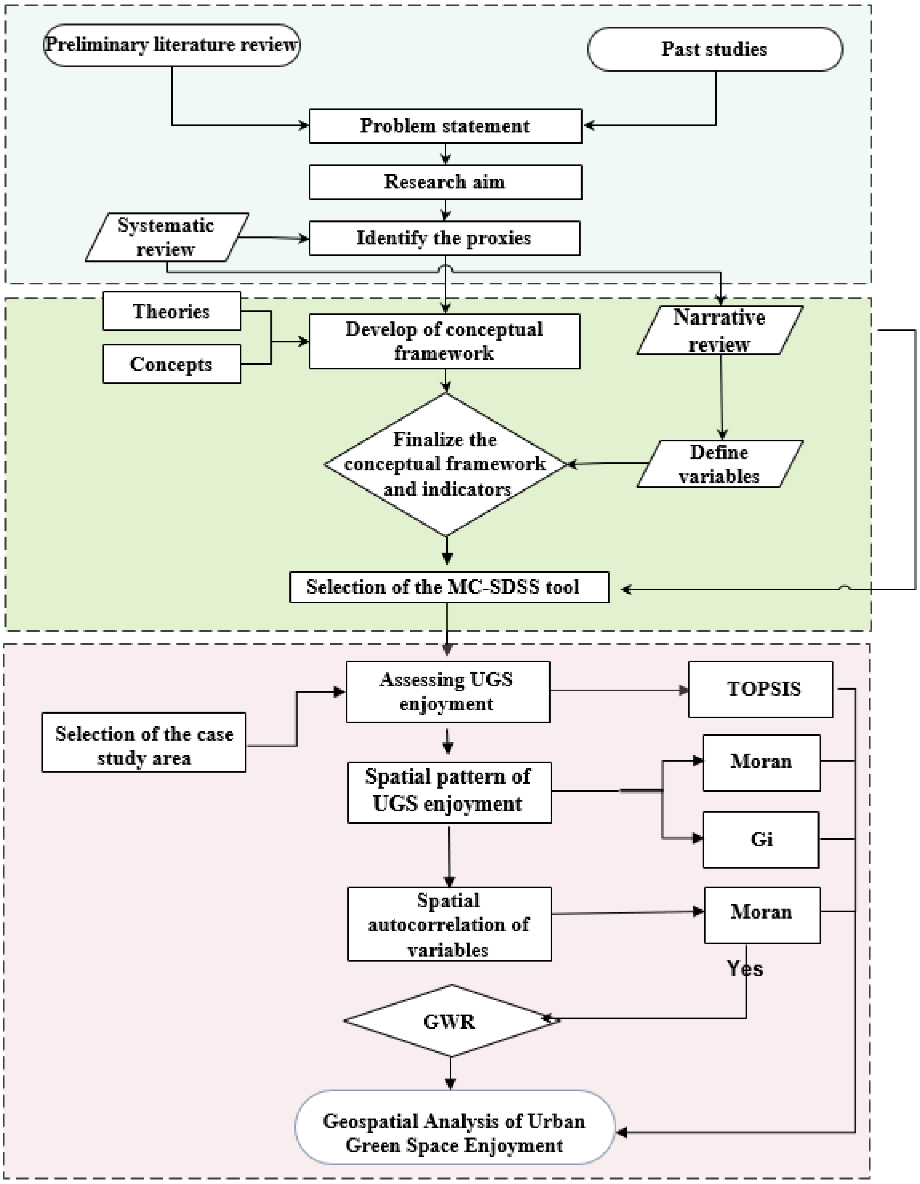

Fig. 2. Research framework
Source: own elaboration

(e.g., area, oxygen production, water resources), (2) Demand & Pressure (e.g., population density, growth rate), and (3) Accessibility & Spatial Equity (e.g., service radius, *per capita* allocation). The indicators, their precise definition, and units are detailed below:

1. Green Space Area (m^2): Total area of formal public green spaces within each district. Justification: Represents the absolute supply of UGS.
2. Proposed Green Space Area (m^2): Area designated for green space in Mashhad's detailed comprehensive plan. Justification: Indicates planning intent and future supply potential.
3. Green Space *per capita* (m^2/person): Ratio of total green space area to district population. Justification: A standard measure of individual share, though it masks intra-district distribution.
4. Ratio of Green Space to Residential Area (%): Proportion of a district's residential zone occupied by green space. Justification: Measures land-use integration and penetration of greenery into living areas.
5. Population Density (persons/km^2): Number of inhabitants per unit area in each district. Justification: A key pressure factor influencing *per capita* access and demand intensity.
6. Population Growth Rate (%/year): Average annual population change. Justification: Captures dynamic demographic pressure on static or slowly evolving UGS infrastructure.
7. Access Radius to Green Spaces (m): Calculated as the average Euclidean distance from the centroid of each residential block to the nearest public park entrance. Green spaces located on the city limits were included if they were publicly accessible and functionally served the adjacent urban population. This method accounts for enclaves by calculating access from within the inhabited portions of each district. Justification: A direct measure of physical accessibility, crucial for actual enjoyment.
8. Water Resources Proxy: Represented by the total length of primary and secondary water canals (for irrigation) within each district (km). In Mashhad's semi-arid context, this infrastructure is critical for maintaining green spaces. Justification: Serves as an indicator of the capacity to sustain green spaces, influencing their quality and survival.
9. Oxygen Production-Consumption Balance (kg/year): Estimated based on the total leaf area of green spaces (derived from area and typical canopy cover coefficients for Mashhad's vegetation) and standardized oxygen production rates, balanced against the oxygen consumption of the district's population. Justification: Provides a biophysical metric of the environmental service (air purification) provided by UGS.

<u>TOPSIS model</u>

TOPSIS is a multi-criterion decision-making method designed to rank and select options based on a variety of features and criteria. As an analytical tool, TOPSIS assists decision-makers in evaluating available options by assessing their proximity to both an ideal and a non-ideal solution. In this method, the criteria and their respective weights are first established. The weight assignment is a critical step, as it reflects the relative importance of each indicator in the overall assessment of UGS enjoyment. In this study, the weights for the nine indicators were determined through an expert judgment approach. Twenty structured questionnaires were distributed among experts in urban planning, environmental science and geographical sciences. The experts performed pairwise comparisons of the indicators using Saaty's standard 1–9 scale of relative importance (Saaty, 1980; Ming Way & Hsu, 2014). The collected responses were aggregated, and the consistency ratio (CR) for each questionnaire was checked to ensure logical judgment. Responses with a CR of less than 0.1 were considered acceptable. The final weight for each indicator (wjwj) was calculated as the geometric mean of the validated expert judgments, ensuring a consensus-based weighting scheme. After establishing the criteria weights, a normalized decision matrix is constructed. Subsequently, the weighted normalized matrix is calculated by multiplying each normalized value by its corresponding criterion weight. Then, the ideal best (A+$A+$) and ideal worst (A−$A-$) solutions are identified for each criterion (where a higher value is desirable for "benefit" criteria and a lower value for "cost" criteria). The Euclidean distances of each alternative (district) from A+$A+$ (Di+$Di+$) and from A−$A-$ (Di−$Di-$) are calculated. Finally, the relative closeness (Closeness Index, CiCi) of each alternative to the ideal solution is computed using the formula Ci=Di−/(Di++Di−)$Ci=Di-/(Di++Di-)$. The districts are then ranked based on their CiCi values, which range from 0 (closest to the worst solution) to 1 (closest to the ideal solution), enabling the identification of the optimal choice and a complete ranking of all districts.

<u>Spatial autocorrelation</u>

Spatial autocorrelation is a valuable analytical tool for understanding how spatial patterns evolve. It classifies spatial patterns as clustered, dispersed or random, focusing on the arrangement of regional units. Strong spatial autocorrelation indicates that the attribute values of geographic phenomena are closely related to one another. Conversely, if the coefficients of geographic phenomena exhibit no specific correlation or discernible order, they are characterized as having weak spatial correlation or a random pattern (Qiu et al., 2022; Griffith, 2023). Common measures of spatial autocorrelation include Moran's I index, which is expressed as:

$$I = \frac{n}{s} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n}(x_i - \overline{x})^2}$$

where:

- x_i and x_j are the attribute values for districts *i* and *j*,
- $\bar{x}$ is the mean of the attribute values,
- *n* is the number of urban districts,
- *s* is the sum of all coefficients,
- w_{ij} is the spatial weight between which ranges from −1 to +1. −1 indicates negative spatial interaction and +1 indicates positive spatial interaction. If there is no spatial interaction, Moran's coefficient is zero.

In the present study, after calculating the level of UGS enjoyment for each district of Mashhad, each criterion was converted into raster data. Following reclassification, their dispersion patterns were analyzed in ArcMap software using Moran's technique to examine the distribution of indicators and their spatial relationships.

While Global Moran's I identifies the type of spatial pattern, Hot Spot Analysis (Getis-Ord Gi statistic) is employed to illustrate the spatial distribution of degradation patterns. The calculated Z-score indicates areas where high or low values are clustered. This index evaluates each feature in the context of its neighboring features, implying that, for a feature to be classified as a statistically significant hot spot, both the feature and its neighbors must exhibit high values (Wang et al., 2021; Fahad et al., 2022). The Getis-Ord Gi statistic is calculated as:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij}\, x_j - \bar{x} \sum_{j=1}^{n} w_{ij}}{s \sqrt{\frac{n \sum_{j=1}^{n} w_{ij}^2 - (\sum_{j=1}^{n} w_{ij})^2}{n-1}}},$$

where:

- x_i is the attribute value for feature *j*,
- w_{ij} is the spatial weight between features *i* and *j*,
- *n* is the total number of features.

$\bar{x}$ is expressed as:

$$\bar{x} = \frac{\sum_{j=1}^{n} x_i}{n}$$

and S is expressed as:

$$s = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{2} - (\bar{x})^2}$$

Geographically Weighted Regression (GWR) is a local spatial statistical technique used to analyze spatial non-stationarity, particularly when the unit of measurement of a variable varies across different locations. This model enables the examination of relationships between variables within a specific geographical context, accounting for local variations (Wheeler, 2021). The GWR model is defined as:

$$\hat{y} = \beta_0(\mu_i\, v_i) + \sum_k \beta_k\, (\mu_i\, v_i) x_{ik} + \varepsilon_i\,,$$

where:

- $(\mu_i v_i)$ are the coordinates of each location *i*,
- $\beta_0(\mu_i v_i)$ is the intercept for location *i*,
- $\beta_k(\mu_i v_i)$ is a local parameter that estimates the independent variable x_k at location *i*,
- ε_i is a random error with the assumption of *N* (0, σ^2) (normality assumption).

3. Research results

3.1. UGS enjoyment in Mashhad districts

The results of the TOPSIS model regarding the level of development in Mashhad's urban districts are presented in Table 1 and Figure 3. Based on the studies and analyses conducted, the urban districts of Mashhad are evaluated concerning green space from a sustainable development perspective and categorized into five groups according to their prioritization of development levels. These classifications are based on the Closeness Index (CI), which reflects the output of the TOPSIS calculations, with an ideal CI value of one. The closer a district's CI value is to one, the more favorable and suitable the district is considered. Conversely, as the CI value decreases further from one, the district's situation becomes increasingly unfavorable. The five-tier classification (Very Developed, Developed, Relatively Developed, Deprived, and Very Deprived) was determined using the Natural Breaks (Jenks) classification method. This data-driven method optimizes the arrangement of values into classes by minimizing the variance within each class and maximizing the variance between classes. It is particularly suitable for identifying inherent groupings in spatial data, such as the distinct tiers of UGS enjoyment found across Mashhad's districts.

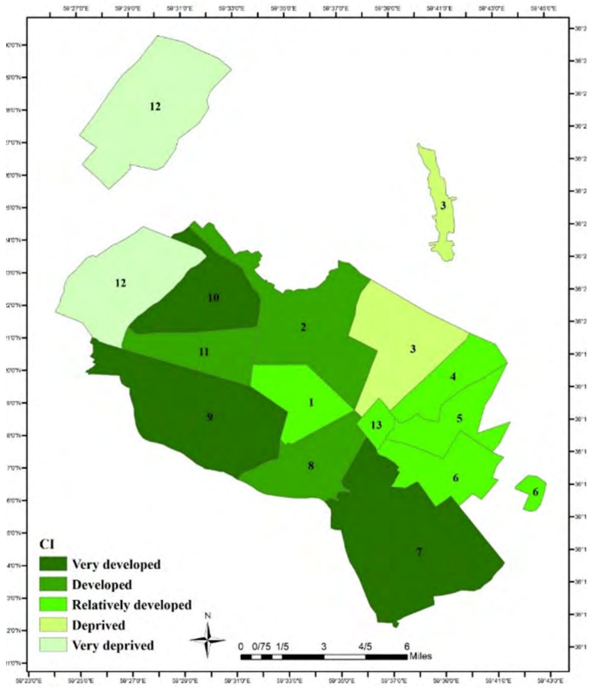

Fig. 3. Levels of UGS enjoyment in Mashhad metropolis districts based on Closeness Index (CI)
Source: own elaboration

- Very Developed Areas: Among the urban districts of Mashhad, three districts are classified as very developed, with an average Closeness Index (CI) of 0.617. District 9 boasts the highest development score, achieving a CI of 0.780, making it the most developed district. It is followed by District 7 in second place and District 10 in third place.
- Developed Areas: The urban districts ranked as developed include Districts 8, 2 and 11, with CIs of 0.489, 0.425 and 0.495, respectively. The average TOPSIS score for this group is 0.469.
- Relatively Developed Areas: This group has an average TOPSIS score of 0.354. District 1 leads with the highest development score of 0.372, while District 13 has the lowest score at 0.334. Areas in this category possess relatively adequate facilities and green spaces and are considered a third priority for planning.
- Deprived Areas: This category is represented by District 3, which has a CI of 0.210. It faces significant shortcomings concerning green space indicators and is classified as the second level of planning priority.
- Very Deprived Areas: District 12, with a CI of 0.0179, is in a very unfavorable and critical situation concerning the evaluated indicators. Undoubtedly, this area should be the highest priority for planning efforts.

Table 1. Overview of UGS enjoyment level in Mashhad metropolis districts based on Closeness Index (CI)

Level of availability	District Number	CI	CI average
Very Developed Areas	9	0.78	0.617
	7	0.536	
	10	0.536	
Developed Areas	11	0.495	0.469
	8	0.489	
	2	0.425	
Relatively Developed Areas	1	0.372	0.354
	6	0.364	
	4	0.358	
	5	0.344	
	13	0.334	
Deprived Areas	3	0.210	0.210
Very Deprived Areas	12	0.179	0.179

Source: own elaboration

3.2. Analysis of the spatial pattern of UGS enjoyment in Mashhad metropolis districts

The application of Moran's Index to the spatial distribution of Urban Green Space (UGS) enjoyment yielded a value of Moran's Index = 0.195543. Since this value is positive and close to one, it indicates the presence of spatial autocorrelation within the data. Additionally, the calculated z-score is 1.948571, which exceeds the expected value of 1.65 at a 95% confidence level. Based on the findings from the global Moran's I, it can be inferred that UGS enjoyment in the districts of Mashhad follows a clustered pattern, meaning that areas with either high or low enjoyment tend to be located adjacent to one another (see Fig. 4).

The G_i index for areas with spatial autocorrelation in this study is 0.0000690 at a 95% confidence level. This value suggests the absence of significant clustering, indicating that there is no discernible hotspot or coldspot pattern at the local level (see Fig. 5).

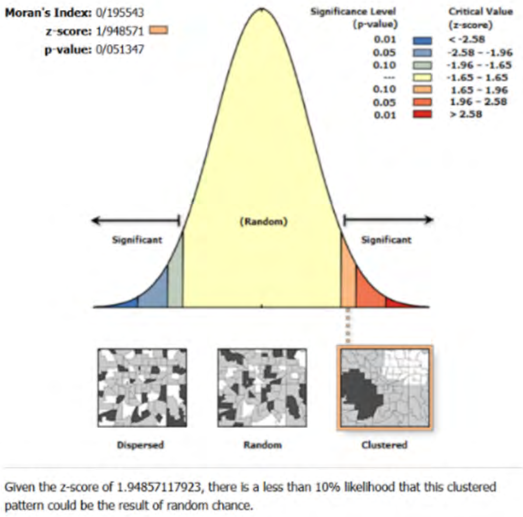

Fig. 4. Statistical results of Moran's test in evaluating the spatial pattern of UGS enjoyment
Source: own elaboration

3.3. Modeling factors affecting UGS enjoyment by GWR

To model the factors affecting UGS enjoyment, Moran's I correlation coefficient was first calculated for all indicators. The results revealed that, among the nine studied variables, two – namely, the green space area and the population growth rate – exhibited spatial autocorrelation. Consequently, the impact of changes in these variables on the districts of Mashhad was further investigated using GWR (Fig. 6).

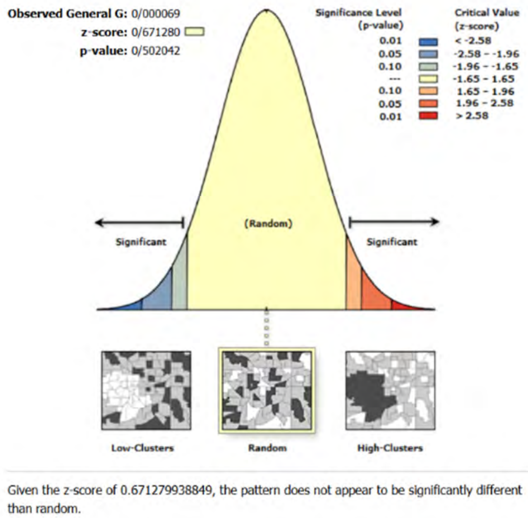

Fig. 5. Statistical results of the G_i test in evaluating the spatial pattern of UGS enjoyment
Source: own elaboration

After running GWR on the model parameters, general information about the model was compiled in Table 2. This table includes statistics that reflect the model's goodness of fit, with the most important values being R2 and Adjusted R2, which assess the accuracy of the model. The closer these values are to one, the better the descriptive variables can predict variations in the dependent variable. According to Table 2, the model in question demonstrates acceptable accuracy in modeling the spatial relationships of factors affecting the level of UGS enjoyment in Mashhad, with an Adjusted R2 value of 0.83.

The GWR analysis on the model variables revealed that the variables of green space area and population growth rate have a significant impact on UGS enjoyment (Fig. 7).

Table 2. Modeling variables of UGS enjoyment in the city of Mashhad by GWR.

Variables	Residual Squares	R^2	Adjusted R^2	AICc(Note 1)
Population growth rate	-0.104810	0.593013	0.56	-15.50
Green space Area	0.033297	0.58333	0.55	-15.19

Source: own elaboration

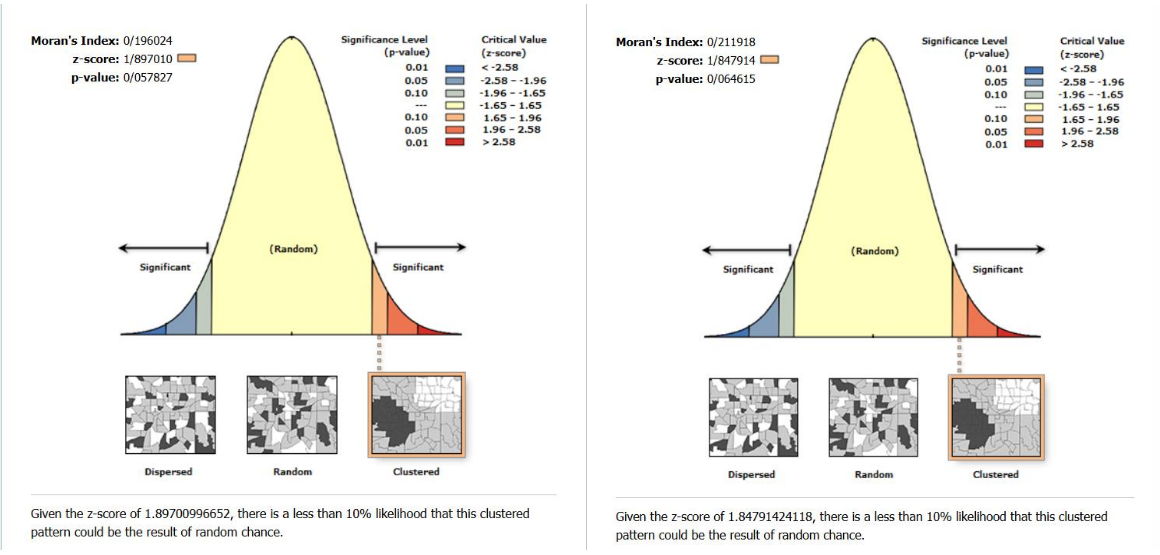

Fig. 6. Statistical results of Moran's test in evaluating the spatial pattern of green spaces area and population growth rate
Source: own elaboration

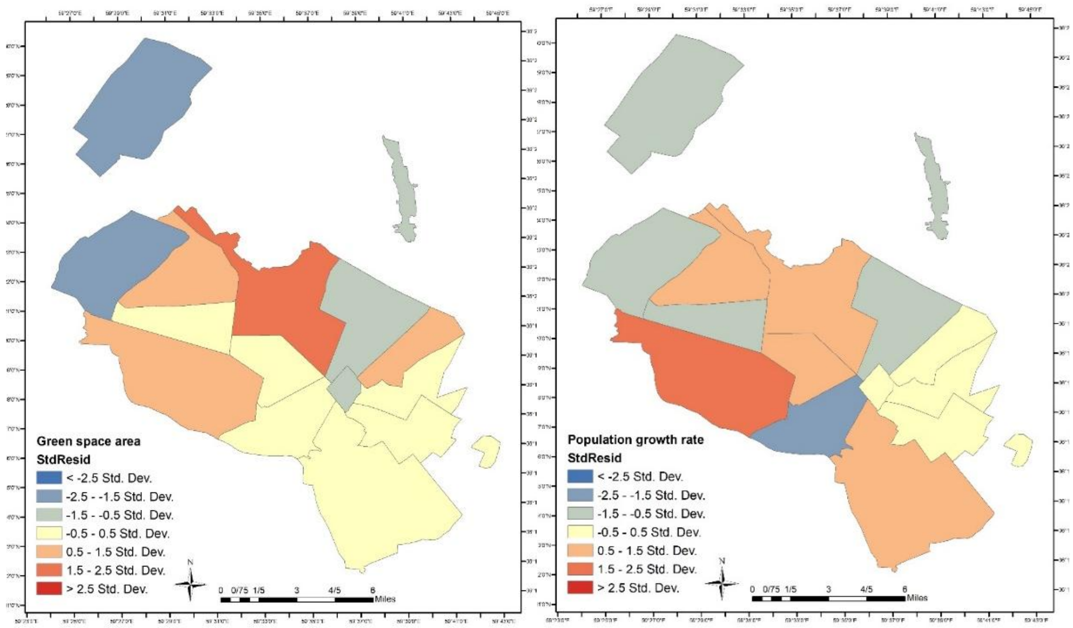

Fig. 7. Spatial variations of green space area and population growth rate and its impact on UGS enjoyment in Mashhad
Source: own elaboration

3.4. Synthesis of key findings

The spatial analysis of UGS enjoyment in Mashhad yields the following key findings:

- Spatial Hierarchy of Development: The TOPSIS model revealed a clear spatial hierarchy across Mashhad's districts. District 9 in the south is the most developed, while Districts 3 and 12 in the north and north-east are classified as the most deprived.
- Clustered yet Non-Polarized Pattern: Global spatial autocorrelation (Moran's I = 0.195) confirms a clustered distribution of UGS enjoyment, meaning districts of similar levels tend to be geographically adjacent. However, the absence of significant local hotspots/coldspots (Gi statistic) indicates that this clustering does not create statistically extreme or isolated pockets of privilege or deprivation at the district level.
- Key Driving Factors: Geographically Weighted Regression identified green space area and population growth rate as the two spatially autocorrelated variables that are locally significant. Together, they explain ~60% of the spatial variation in UGS enjoyment, highlighting the critical imbalance between demographic pressure and green infrastructure provision.
- Spatial Non-Stationarity: The strength and direction of the relationship between the key drivers (area, population growth) and UGS enjoyment vary across the city, as captured by the GWR model. This indicates that the factors influencing access are location-specific, necessitating tailored local planning interventions rather than a one-size-fits-all policy.

4. Discussion and conclusions

The TOPSIS technique was used to assess UGS enjoyment in Mashhad's 13 districts. The results indicate varying levels of enjoyment across the metropolis, with southern and western districts generally more endowed and northern and north-eastern districts less so. This result of the study is in line with studies by Bielecka et al. (2018) and Alrikabi & Almosherefawi (2021), who likewise concluded that UGS distribution varies significantly among urban districts, affecting *per capita* allocation.

The distribution analysis of the level of UGS enjoyment was carried out using the global Moran coefficient and the local Gi index in Geographic Information Systems (GIS). It proves valuable for analyzing and visualizing the spatial distribution of green areas, aiding in urban planning and policy development (Dimyati et al., 2018; Alrikabi & Almosherefawi, 2021).

The global Moran's I coefficient for UGS enjoyment among Mashhad's districts is 0.195543 at a 95% confidence level, indicating spatial correlation among the urban areas. The Gi index is 0.000069, suggesting no significant hotspots or coldspots in Mashhad's districts. This indicates that, while the overall distribution of green space is clustered, there are no specific areas with significantly higher or lower levels of enjoyment. The distribution is unexpectedly uniform at the local level. The differences in results stem from the analytical approaches of each index:

Moran's I consider relationships between all data points, indicating overall spatial correlation. Gi is designed to examine local details and identify specific areas with significant features. Thus, while Moran's I indicates a correlation, Gi suggests that this correlation does not result in significant differences across the city. This outcome has both positive and negative implications:

Positive Aspects:

1. Equitable Distribution: Despite neglecting the qualitative aspects of Mashhad's urban green spaces and the average *per capita* distance to the ideal, the absence of significant spatial disparities in UGS enjoyment suggests a relatively fair distribution, promoting spatial justice in access to UGS for citizens.
2. Lack of Inequality: The lack of identifiable hotspots or coldspots indicates that there are no significant inequalities in access to UGS across different districts.
3. Sustainable Expansion: Despite considerable physical and spatial development through organic growth and urban sprawl, the distribution of minimum *per capita* green space reflects an awareness of sustainability in UGS during the city's expansion.
4. Endowment Ownership: Large-scale green spaces with endowment ownership have historically helped protect and stabilize urban green spaces, especially in central and strategic areas. This has played a significant role in balancing the distribution of *per capita* green space for the public good and reducing severe spatial imbalances.

Negative Aspects:

1. Neglect of Specific Needs: A uniform distribution of green spaces may overlook the specific needs of certain areas – particularly, densely populated or disadvantaged neighborhoods – that may require more green space.

2. Lack of Diversity: The absence of hotspots might imply that some areas lack unique features in green spaces, potentially diminishing environmental diversity and the area's overall appeal.

Spatial analysis of urban green spaces reveals important insights into their distribution and impact. Multiple studies have found that green spaces tend to be clustered and unevenly distributed within cities (Dimyati et al., 2018; Bielecka et al., 2018; Alrikabi & Almosherefawi, 2021). Moran's I index is commonly used to assess spatial autocorrelation, with values indicating clustering or randomness in distribution (Bielecka et al., 2018; Dimyati et al., 2018; Rahnama & Shaddel, 2019).

The spatial diagnosis provided by this study offers several concrete implications for urban planning and policy in Mashhad:

- Targeted Investment in Deprived Clusters: Resources for new parks, park upgrades, and green infrastructure should be strategically funneled into the identified deprived cluster in the north and north-east (Districts 3 and 12 and their adjacent areas). General city-wide *per capita* targets are insufficient to address this spatially entrenched inequality.
- Green Space–Growth Nexus Regulations: The strong explanatory power of population growth rate necessitates new policy instruments. Municipal bylaws should mandate proportional green space provision tied to new residential or commercial development approvals, ensuring infrastructure keeps pace with demographic expansion.
- Leveraging Endowment Lands: The stabilizing role of large endowment-owned green spaces (e.g., around the Holy Shrine) should be formally recognized and leveraged. Partnerships with endowment foundations could be established to improve public access and management, using these central green anchors to enhance connectivity to deprived northern districts.
- Neighborhood-Scale Planning: The district-level analysis, while revealing, may mask micro-scale inequities. Planners should use these findings to launch finer-grained, neighborhood-level audits within deprived districts to identify specific underserved blocks and design hyper-local interventions like pocket parks or street greening.

This study has limitations that frame the interpretation of its results and point to future research avenues:

- Data Resolution and Scope: The analysis was conducted at the district level. While appropriate for city-wide policy, this administrative scale may obscure significant inequalities in access, quality and perception within districts, particularly in large or heterogeneous ones. Future studies should employ higher-resolution data (neighborhood or block level).
- Temporal Scope: The study provides a cross-sectional snapshot for 2023. A longitudinal analysis tracking changes in UGS distribution against population growth and planning interventions over time would be invaluable for assessing policy effectiveness and understanding dynamic trends.
- Qualitative Dimensions: The indicators primarily capture quantitative and spatial aspects (area, distance, density). Integrating qualitative metrics, such as perceived safety, maintenance quality, biodiversity or user satisfaction, would provide a more holistic understanding of UGS "enjoyment" and its drivers.

Determining the distribution of service centers, including green spaces and parks, is a common challenge for planners striving to guide resource and service allocation. Therefore, selecting appropriate indicators is the first step in assessing the development levels of different areas. In this study, nine selected indicators were ranked using the TOPSIS model, leading to the categorization of the development levels of UGS in the districts of Mashhad into five categories: very developed, developed, relatively developed, deprived, and very deprived. The key findings are as follows:

- Categorization of Districts: Mashhad's districts have been classified into five development levels based on the selected indicators.
- Developed Districts: Districts 7, 9 and 10 are considered developed, with an average Closeness Index (CI) of 0.617.
- Developing Districts: Districts 2, 8 and 11 fall under the developed level, with an average CI of 0.469.
- Relatively Developed Districts: Districts 1, 4, 5, 6 and 13 are classified as relatively developed, with an average CI of 0.354.
- Deprived Districts: District 3 is categorized as deprived, with an average CI of 0.210.
- Very Deprived Districts: District 12 is considered one of the most deprived areas, having an average CI of 0.179.

Developing structural strategies and attracting investment in deprived and relatively deprived areas can significantly enhance sustainable urban development and improve green space infrastructure, thereby reducing social inequality.

Next, global Moran's I and local Gi coefficients were calculated for the research criteria to determine the spatial distribution of UGS enjoyment across the districts. The calculations showed that, at a 95% confidence level, the global Moran's I index is 0.195543, indicating that UGS enjoyment is generally clustered and exhibits some spatial autocorrelation. Conversely, the local Gi index is 0.000069, suggesting that the correlation between districts is not strong enough to create distinct hotspots or coldspots. These findings imply that, while the overall distribution of green spaces is clustered at the urban level, these clusters do not necessarily create significant or distinct areas. Instead, they exhibit an unexpected and subtle variation in distribution at the local level, indicating a uniform distribution of green space across the city. Thus, it can be concluded that Mashhad's districts do not exhibit significant spatial differences concerning UGS enjoyment.

In light of this, it is suggested that future studies focus on the distribution patterns of UGS enjoyment in sub-districts and neighborhoods to better identify locations for future UGS development. This should be based on the hotspots and coldspots that may arise at the neighborhood level. To model the factors affecting the level of UGS enjoyment in Mashhad's districts, the correlation of each variable was initially calculated. The research results showed that the population growth rate and green space area have spatial correlations, with coefficients of determination of 0.58 and 0.59, respectively. Therefore, it can be concluded that ~60% of the variation in UGS enjoyment in Mashhad is explained by these two variables. A key contribution of this study is its demonstration of a replicable, integrated MC-SDSS framework for urban green space assessment. By combining multi-criterion decision-making with spatial statistics and local regression modeling, the study moves beyond simple *per capita* metrics to provide a nuanced spatial diagnosis of equity. Thereby filling a gap in literature focused on cities in the Global South with unique demographic and environmental pressures, the methodological approach applied here is readily transferable to other cities, especially in the Global South, facing similar challenges of rapid urbanization and green space provision.

Note

1. Akaike Information Criterion (AIC): This is a very useful indicator for comparing regression models. A lower AIC value indicates a better fit of the model to the observed data.

References

Alrikabi, N.K., & Almosherefawi, O.J. (2021). Reality analysis of the state of the spatial distribution of green areas using geographic information systems (GIS) – The holy city of Najaf as a case study. In: *IOP Conference Series: Earth and Environmental Science,* 754(1), 012009. IOP Publishing. https://doi.org/10.1088/1755-1315/754/1/012009

Anteneh, M.B., Damte, D.S., Abate, S.G., & Gedefaw, A.A. (2023). Geospatial assessment of urban green space using multi-criteria decision analysis in Debre Markos City, Ethiopia. *Environmental Systems Research*, 12(1), 7. https://doi.org/10.1186/s40068-023-00291-x

Athokpam, V., Chamroy, T., & Ngairangbam, H. (2024). The role of urban green spaces in mitigating climate change: An integrative review of ecological, social, and health benefits. *Environmental Reports,* 10-14. https://doi.org/10.51470/er.2024.6.1.10

Awuah, K.G.B., & Abdulai, R.T. (2022). Urban land and development management in a challenged developing world: An overview of new reflections. *Land*, 11(1), 129. https://doi.org/10.3390/land11010129

Bardhan, R., Debnath, R., & Bandopadhyay, S. (2016). A conceptual model for identifying the risk susceptibility of urban green spaces using geospatial techniques. *Modeling Earth Systems and Environment*, 2, 1–12. https://doi.org/10.1007/s40808-016-0202-y

Baycan, T., van Leeuwen, E.S., Rodenburg, C.A., & Nijkamp, P. (2002). *Development and management of green spaces in European cities: A comparative analysis*. (Research Memorandum; No. 2002-25). FEWEB.

Bielecka, E., Calka, B., & Bitner, A. (2018). Spatial distribution of urban greenery in Warsaw: A quantitative approach. In: *Proceedings of 7th International Conference on Cartography and GIS.*

Biernacka, M. (2020). Przegląd i ocena wybranych wskaźników dostępności i atrakcyjności miejskich terenów zieleni (Review and assessment of selected indicators of accessibility and attractiveness of urban green spaces – in Polish). *Acta Universitatis Lodziensis. Folia Oeconomica*, 2(346), 53–70. https://doi.org/10.18778/0208-6018.347.04

Campagnaro, T., Sitzia, T., Cambria, V.E., & Semenzato, P. (2019). Indicators for the planning and management of urban green spaces: A focus on public areas in Padua, Italy. *Sustaina-*

bility (Switzerland), 11(24), 7071. https://doi.org/10.3390/su11247071

Chen, J., Kinoshita, T., Li, H., Luo, S., & Su, D. (2024). Which green is more equitable? A study of urban green space equity based on morphological spatial patterns. *Urban Forestry & Urban Greening*, 91, 128178. https://doi.org/10.1016/j.ufug.2023.128178

Correia, C.R., & Roseland, M. (2022). Addressing negative externalities of urban development: Toward a more sustainable approach. *Urban Science*, 6(2), 38. https://doi.org/10.3390/urbansci6020038

Dimyati, M., Fauzy, A., & Putra, A.S. (2018). Spatial pattern analysis and identification type of open green space in Yogyakarta city. In: *MATEC Web of Conferences*, 197, 03004. EDP Sciences. https://doi.org/10.1051/MATECCONF/201819703004

Escalante, A.Y.R., Sandoval, D.A., Bustillos, E.V., & Zezzatti, C.A.O.O. (2020). A multi-criteria decision making for sustainable location of urban parks. *Research in Computing Science*, 149(6), 5–20.

Fahad, M.G.R., Zech, W.C., Nazari, R., & Karimi, M. (2022). Developing a geospatial framework for severe occupational injuries using Moran's I and Getis-Ord Gi statistics for southeastern United States. *Natural Hazards Review*, 23(3), 04022020. https://doi.org/10.1061/(asce)nh.1527-6996.0000566

Griffith, D.A. (2023). Art, geography/GIScience, and mathematics: A surprising interface. *Annals of the American Association of Geographers*, 113(1), 1–12.

Halecki, W., Stachura, T., Fudała, W., Stec, A., & Kuboń, S. (2023). Assessment and planning of green spaces in urban parks: A review. *Sustainable Cities and Society*, 88, 104280. https://doi.org/10.1016/j.scs.2022.104280

Jain, A.K. (2024). Urban green spaces and their role in enhancing quality of life. *i-Manager's Journal on Structural Engineering*, 12(4), 33. https://doi.org/10.26634/jste.12.4.20986

Karade, R.M., Kuchi, V.S., & Kabir, J. (2013). The role of green space for sustainable landscape development in urban areas. In: *IV International Conference on Landscape and Urban Horticulture*, 1181, 73–76. https://doi.org/10.17660/ActaHortic.2017.1181.9

Kaur, N., Kaur, M., Padhi, S.S., & Singh, K.K. (2022). Geospatial analysis of the distribution of urban green spaces: A study of four Indian cities. *Cities & Health*, 6(3), 443–459. https://doi.org/10.1080/23748834.2021.1941722

Kiamba, A. (2012). The sustainability of urban development in developing economies. *Consilience*, 8, 20–25. https://www.jstor.org/stable/26188711

Li, W. (2023). Urban landscape green space management and sustainable development. *Journal of Civil Engineering and Urban Planning*, 5(12), 48–52. https://doi.org/10.23977/jceup.2023.051207

Mashhad Municipality. (2007). Statistics of Mashhad, 2006. Assistance of Planning and Human Capital Development of Mashhad Municipality, Statistics Management.

Mashhad Municipality. (2022). *Statistics of Mashhad, 2021*. Assistance of Planning and Human Capital Development of Mashhad Municipality, Statistics Management.

Mostafapour, M., Ghafari Gilandeh, A., & Yazdani, M.H. (2015). *An analysis on the style of spatial arrangement of user green spatial and proposing an appropriate pattern using MCDM: Case study of Ardabil city*. PhD Thesis. University of Mohaghegh Ardabili.

Núñez, J.M. (2021). Análisis espacial de las áreas verdes urbanas de la Ciudad de México (Spatial analysis of urban green areas in Mexico City – in Spanish). *Economía, sociedad y territorio*, 21(67), 803–833. https://doi.org/10.22136/EST20211661

Pilehvar, A. (2021). Spatial-geographical analysis of urbanization in Iran. *Humanities and Social Sciences Communications*, 8(1), 1–12. https://doi.org/10.1057/s41599-021-00741-w

Pirmoradian, F., & Ashtari, I. (2020). Investigation of socio-economic and environmental functions of urban green space. *International Journal of Ecosystems & Ecology Sciences*, 10(1). https://doi.org/10.31407/ijees10.124

Qiu, M., Zuo, Q., Wu, Q., Yang, Z., & Zhang, J. (2022). Water ecological security assessment and spatial autocorrelation analysis of prefectural regions involved in the Yellow River Basin. *Scientific Reports*, 12(1), 5105. https://doi.org/10.1038/s41598-022-07656-9

Rahnama, M.R., & Shaddel, L. (2019). Urban green space is spatially associated with cardiovascular disease occurrence in women of Mashhad: A spatial analysis of influential factors on their presence in urban green spaces. *Journal of Urban Health*, 96(5), 653–668. https://doi.org/10.1007/s11524-019-00373-1

Ramaiah, M., & Avtar, R. (2019). Urban green spaces and their need in cities of rapidly urbanizing India: A review. *Urban Science*, 3(3), 94. https://doi.org/10.3390/URBANSCI3030094

Sabet teimouri, M.S., Forghani, A., & Baghban, S. (2022). A geospatial analysis approach for mapping and ranking of tourist corridors in Mashhad Metropolis, Iran. *World Journal of Geomatics and Geosciences*, 2(1), 1–23.

Santos, P.A.S., Cortez, B., & Carvalho, M.T.M. (2025). Integrating GIS and BIM with MCDM for infrastructure planning: A comprehensive framework. *Engineering, Construction and Architectural Management*, 32(6), 4197–4226. https://doi.org/10.1108/ECAM-08-2023-0830

Smith, D.O. (2019). *Third world cities in global perspective: The political economy of uneven urbanization*. Routledge. https://doi.org/10.4324/9780429495663

Teimouri, R., Karuppannan, S., Sivam, A., Gu, N., & Yenneti, K. (2023). Exploring international perspective on factors affecting urban socio-ecological sustainability by green space planning. *Sustainability (Switzerland)*, 15(19), 14169. https://doi.org/10.3390/su151914169

Teimouri, R., & Yigitcanlar, T. (2018). An approach towards effective ecological planning: Quantitative analysis of urban green space characteristics. *Global Journal of Environmental Science and Management*, 4(2), 195–206. https://doi.org/10.22034/gjesm.2018.04.02.007

United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development*. https://sdgs.un.org/2030agenda

Wang, S., Bao, Z., Culpepper, J.S., & Cong, G. (2021). A survey on trajectory data management, analytics, and learning. *ACM Computing Surveys (CSUR)*, 54(2), 1–36. https://dl.acm.org/doi/10.1145/3440207

Wheatley, M.C. (2024). The impact of mega-events on urban development: A review. *Premier Journal of Environmental Science,* 2024(1), 100001. https://doi.org/10.70389/PJSS.100001

Wheeler, D.C. (2021). Geographically weighted regression. In *Handbook of regional science*. Springer Berlin Heidelberg.

Zhang, F., & Qian, H. (2024). A comprehensive review of the environmental benefits of urban green spaces. *Environmental Research*, 118837. https://doi.org/10.1016/j.envres.2024.118837

Zhang, L., Wang, Z., & Da, L. (2019). Spatial characteristics of urban green space: A case study of Shanghai, China. *Applied Ecology & Environmental Research*, 17(2), 1799–1815. https://doi.org/10.15666/AEER/1702_17991815