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Assessing green space indicators: A case study of Sarajevo, Bosnia and Herzegovina

The main objectives of this study were to 1) assess the following quantitative urban green space (UGS) indicators: share of UGS, total UGS per capita, and the public UGS per capita for Sarajevo and its corresponding municipalities; 2) propose the minimum area of UGS per capita and the minimum functional UGS area per capita; and 3) discuss the methodological approach used and its applicability and relevance for UGS quantity and quality assessment. UGSs were photo-interpreted based on orthophotos and Google Satellite images and mapped manually. The total UGS area for Sarajevo is 58.5 km², with continuous green spaces present in hilly and mountainous areas of the city, whereas more built-up zones are present in flat areas. The total public UGS per capita is 28.0 m², or 9.8 m² if forest parks are excluded. The results can help in better understanding UGSs in Sarajevo and can serve as a reference for decisionmakers and policymakers.

Keywords: quantification of green space, unsupervised classification, green space classes, urban green spaces

1 Introduction

Urban green spaces (UGSs) are defined as places with "natural surfaces" or "natural settings", including specific types of urban greenery, such as street trees (World Health Organization, 2016), encompassing public and private open spaces in urban areas, primarily covered by vegetation (Hernandes et al., 2018), regardless of their size and function (Pinto et al., 2022). UGSs are regarded as a critical element for the quality of life of urban residents. These areas provide aesthetically appealing spaces for community engagement that encourage social interaction and a sense of belonging among the population (Cattell et al., 2008; Peters et al., 2010; Thompson et al., 2016). Access to green spaces is associated with reduced stress, anxiety, and depression, thereby contributing to improved mental wellbeing, while also providing open spaces that promote physical activity, which enhances public health (Tzoulas et al., 2007; Barton & Pretty, 2010). From an ecological perspective, UGSs significantly contribute to reducing the negative impacts of climate change on urban areas. They mitigate the effects of urban heat islands by creating cooler microclimates, reduce energy use through shade, improve air quality, and sequester carbon dioxide from the atmosphere (Nowak & Dwyer, 2007; Tzoulas et al., 2007; Bowler et al., 2010). Furthermore, they assist in managing stormwater and reduce the risk of flooding (Lennon et al., 2014). In addition, UGSs support biodiversity and improve habitat connectivity (Farinha-Marques et al., 2017). For the purpose of this research, UGSs encompass the comprehensive system of areas within an urban setting that is predominately covered by vegetation because all types of UGSs collectively play a vital role in providing their overall functions.

Special urban planning and project implementation should aim to develop a quality urban green infrastructure with an optimal quantity, quality, and spatial structure of greenery to provide urban residents with numerous benefits from UGSs. The standards approach is conventionally used to attain consistency and certainty in UGS planning (Maryanti et al., 2017). UGS standards play a role in the development of urban green infrastructure and effective land-use planning, which help support the biological and ecological functions of urban environments (Vujković, 2003). Understanding basic UGS indicators, such as the share of UGS, the total UGS per capita, the total public UGS per capita, and UGS classification contributes to addressing broader global challenges related to sustainability, public health, and social equity. Assessments guide urban planners in establishing targets, allocating resources, and designing spaces that promote urban green infrastructure. Assessing the share of UGS is important for analysing the overall state of urban greenery as well as for making decisions about building restrictions. A larger share of UGS in the total urban environment is associated with various advantages, such as reduced urban heat island effects, enhanced biodiversity, and improved overall health of residents (Maas et al., 2006; Tzoulas et al., 2007; Bowler et al., 2010). Total UGS per capita provides a quantitative measure of all types of green spaces available to residents. Total public UGS per capita is a quantitative indicator of the green space accessibility for all residents. Specifically, it can reveal inequalities in access to recreational and relaxational opportunities. Tracking this metric allows cities to develop policies that address inequalities, ensuring that all residents, regardless of socioeconomic status, can benefit from green spaces.

In Sarajevo, Bosnia and Herzegovina, there are insufficient data on UGS in terms of both quantity and quality (Ballian et al., 2021). Similar results have been reported for several small European cities and towns (Feltynowski & Kronenberg, 2020). The spatial planning of Sarajevo varies among municipalities, which stems from their functional roles and historical development. Sarajevo is the central administrative unit, consisting of four urban municipalities: Stari Grad, Centar, Novo Sarajevo, and Novi Grad, each with its own local administration. The Sarajevo Canton is one of the ten cantons in the Federation of Bosnia and Herzegovina, and it comprises nine municipalities in total, four of which are part of Sarajevo. Changes in detailed spatial plans within municipalities often reduce UGSs in favour of demand for construction land. Given this context, it is important to investigate the quantity, spatial distribution, and UGS types among municipalities, with the aim of ensuring the adoption of standards that are tailored to the local needs and characteristics of individual municipalities.

The current UGS standards for Sarajevo can be found in the Spatial Plan of the City of Sarajevo for the Period from 1986 to 2015 (SCr. *Urbanistički plan grada Sarajeva za urbano područje Sarajevo za period od 1986. do 2015. godine*, Sl. N. GS, no. 7/86). Measurable information on the structure, quantity and spatial distribution of UGSs is one of the prerequisites for determining standards that are applicable in sustainable urban spatial planning. In an earlier relevant study of the city (Zavod, 1985), the standard of public UGSs was proposed to be 25 to 30 m^2 per capita, or 130 m^2 per capita if forest parks are included. The goal, which was set to be accomplished for all UGS classes by 2015, was 47.9 m^2 per capita (Urbanistički, Sl. N. GS, no. 7/86). The standard values of UGSs in the class of apartment buildings were between 6 and 8 m^2 per capita, and 20 m^2 per capita was determined for all individual houses in urban areas. The adopted standard for limited access and special purpose green spaces accounted for 30% to 50% of the total UGS.

It can be assumed that standards that were adapted at the city level based on environmental conditions need to be reassessed in the case of Sarajevo. With respect to the growing pressure

Table 1: Basic information about the municipalities of Sarajevo.

Municipality	Area (km²)		Coordinates	Elevation, m	Population*
	Total	Urban			
Stari Grad	51.4	12.9	43°51′33″ N 18°25′57″ E	540–1,500	35,015
Centar	33.0	16.0	43°52′08″ N 18°24′31″ E	531–1,386	53,333
Novo Sarajevo	9.9	9.9	43°50′51″ N 18°21′23″ E	519–816	63,871
Novi Grad	47.2	47.2	43°51′09″ N 18°23′07″ E	482–850	122,751

*Data obtained from the Federal Bureau of Statistics (Federalni zavod za statistiku, 2020).

of traffic, climate change effects, increased urban densification, and the financial circumstances of urban residents in critical situations such as epidemic crises and energy crises, there is increasing pressure on environmental quality. Therefore, the possible need to increase the area of green spaces is anticipated. Information on the current state and quality of green areas is crucial for assessing minimum values and recommending standards.

This study assesses UGS indicators (the share of UGS, the total UGS per capita, and the public UGS per capita) for Sarajevo. Furthermore, it proposes a minimum area of UGS per capita and further determine the minimum functional UGS area per capita. In addition, it discusses the methodological approach used and its applicability and relevance for UGS quantity and quality assessment.

2 Materials and methods

2.1 Study area

The study area was the urban part of Sarajevo, which is located in the southeastern part of Bosnia and Herzegovina and administratively belongs to the Sarajevo Canton. The total area is 141 km², or 11% of the territory of the Sarajevo Canton (Table 1). The study area spatially encompasses the urban area of the four central municipalities defined by the Spatial Plan of the Sarajevo Canton for 2003–2023 (SCr. *Prostorni plan Kantona Sarajevo za period 2003–2023.*, Sl. N. KS, no. 26/06), specifically the municipalities of Stari Grad, Centar, Novo Sarajevo, and Novi Grad, which together constitute Sarajevo. The city borders the municipalities of Vogošća and Ilijaš to the north and northwest, and the municipality of Ilidža to the west, and the southern and eastern borders are the Republika Srpska (Figure 1). The elevations of the vertical profile range from 482 m in the valley of the Bosna River to 1,534 m on Mount Bukovik. The city centre is located at an average elevation of 511 m. Due to the vertical dispersion of the relief, the slope and valley parts of the city are distinguished, which leads to differences in the microclimate of individual settlements; these differences can cause temperature inversions, a reduction

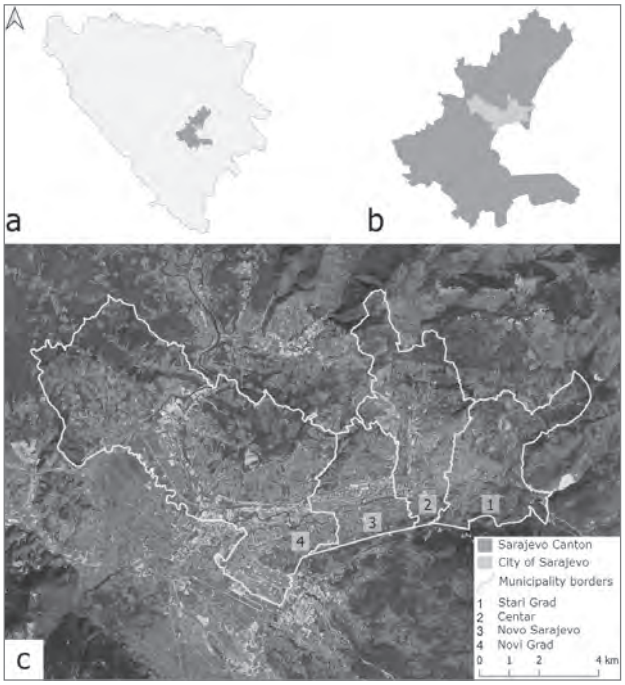

Figure 1: a) location of the Sarajevo Canton within Bosnia and Herzegovina; b) location of Sarajevo within the Sarajevo Canton; c) four municipalities in the urban area of Sarajevo (source: Google Satellite, 2022).

in the intensity and frequency of winds, the occurrence of local winds, and a contribution to the urban heat island effect (Općina Novo Sarajevo, 2023).

2.2 Sentinel-2A satellite image analysis

Sentinel-2A satellite images were used in this research to compare the results of the unsupervised classification with the total urban green space obtained by photointerpretation and manual vectorization of UGSs. We used 99.5% cloud-free, orthorectified, and radiometrically corrected (processing level 1C) S2A images of the study area. These images were acquired in July 2020 and were provided by the Copernicus Sentinels Scientific Data Hub (https://scihub.copernicus.eu/dhus/). Four types of vegetation characterizing 10 m spectral bands were used: blue, green, red, and infrared. The method of

Table 2: UGS classification.

Public UGSs	Limited-access UGSs	Special-purpose UGSs
Large parks	Around facilities and structures	Cemeteries
Forest parks	• Sports and recreation	Plant nurseries
Small parks	• Education	
Roadside green spaces	• Health	
Along watercourses	• Industrial	
Around apartment buildings	• Religious	
	• Institutions	
	• Commercial	
	• Individual houses	
	Urban forests	
	Agricultural land	
	Specialized parks	
	• Arboretums	
	• Zoos	
	• Botanical gardens	
	• Memorial parks	

Source: Vujković (2003).

unsupervised classification (hill climbing, $k = 2$, normalized) of the Sentinel-2 satellite images was applied using SAGA-GIS software to obtain a binary classification of land cover: vegetation and non-vegetation. Areas classified as vegetation were converted into vector polygons.

2.3 Visual interpretation, manual vectorization of orthophoto images, and UGS classification

Orthophoto images of the study area, dating from June 2009 and with a 0.5 m resolution, were used as a primary base for the manual vectorization of urban green spaces (Zavod, 2024). Additional tools used for vectorization and UGS classification were Google Hybrid data, integrated in QGIS software and geodata from the government website Geoportal.ba from March to May 2022. The UGSs were manually polygonized using QGIS software. Each polygon was subsequently assigned a corresponding UGS class based on the categories presented in Table 2, integrating spatial data with the in-depth knowledge about the urban area contributed by the experts involved, and ensuring a comprehensive understanding of the area's characteristics.

The UGSs were classified into three large groups that compose urban green infrastructure: 1) public UGSs, 2) UGSs with limited access, and 3) UGSs with special purposes (Table 2), following the classification given by Vujković (2003). Classification is based on the differences in land and green space use, the functions of green spaces in the urban structure, and the spatial arrangement of green spaces. Public urban green spaces are considered the most important element of urban green infrastructure because they provide almost all the main functions, especially social functions. They are central places of gathering and social interaction for residents, provide recreation services, and are usually distributed such that they are accessible to a larger proportion of the urban population. Urban green spaces with limited access include green areas for which the population has limited access due to the character of the space, special categories of users, entrance fees, and so on. The functions of these green spaces include aesthetics, culture, education, and recreation, in addition to ecological functions. Urban green spaces with special purposes are represented by classes of special functions, such as regulating (e.g., water protection zones), cultural (e.g., cemeteries), or provisioning (e.g., plant nurseries).

Large parks are public green spaces greater than 1.5 hectares, and small parks are less than 1.5 hectares. Roadside green spaces are landscaped areas adjacent to roadways, including road verges, median strips, and buffer zones. Green spaces along watercourses are landscaped areas next to bodies of water, designed to prevent erosion, improve water quality, and provide natural habitats for wildlife and recreational opportunities for the community. Green spaces around apartment buildings contribute to residents' wellbeing by offering areas for relaxation, outdoor activities, and community interaction. Forest parks are wooded areas combining preserved forest habitats with a variety of recreational facilities for outdoor activities. Cemeteries are important green spaces that offer serene environments for reflection and contemplation. Plant nurseries are used to produce plant material in open spaces. Green spaces around sports and recreation facilities provide natural surroundings for sports complexes and outdoor activity areas,

offering environments for relaxation, social interaction, and additional activities. Green spaces around educational facilities provide natural environments adjacent to schools, universities, and other educational institutions, enhancing the educational experience by promoting outdoor learning, physical activity, and social interaction. Green spaces around health facilities provide natural environments adjacent to hospitals and clinics that promote relaxation and recovery, and enhance mental wellbeing. Green spaces around industrial facilities neutralize negative impacts of production on surrounding areas. Green spaces around religious facilities enhance the surroundings of places of worship, providing tranquil environments for reflection and community gatherings. Green spaces around commercial facilities enhance the surroundings of businesses and shopping centres by providing pleasant environments for customers and employees, creating inviting outdoor spaces for relaxation and social interaction. Green spaces around individual houses are predominantly private yards on the outskirts of urban areas. Urban forests are densely wooded areas that maintain a natural landscape with minimal human intervention, prioritizing the preservation of existing ecosystems and playing a vital role in enhancing urban ecology. Agricultural land in urban areas includes community gardens, urban farms, and other green spaces dedicated for food production, contributing to promoting local food systems and enhancing food security. Specialized parks are landscaped areas that focus on specific themes or purposes. These include arboretums, zoos, botanical gardens, and memorial parks.

2.4 The standards approach: Determining green space indicators

This study analyses the following quantitative green space indicators: the share of UGS in the total urban area (%), total UGS per capita (m^2), and public UGS per capita (m^2). The share of UGS characterizes the ecological and biological effectiveness of greenery. It is determined by the ratio of the total area of UGS to the total urban area (Equation 1).

$$\text{Share of UGS} = \frac{\text{total area of UGS}}{\text{total urban area}} \times 100 \quad (\%) \quad \text{(Equation 1)}$$

Total UGS per capita is determined by the ratio of the total area of UGS to the population of the urban area (Equation 2).

$$\text{Total UGS per capita} = \frac{\text{total area of UGS}}{\text{population}} \quad (m^2 \text{ per capita}) \text{ (Equation 2)}$$

Public UGS per capita is used to evaluate the social effectiveness of greenery. It is determined by the ratio of the total area of public green spaces to the population of the urban area (Equation 3).

$$\text{Public UGS per capita} = \frac{\text{total area of public green spaces}}{\text{population}} \quad (m^2 \text{ per capita}) \text{ (Equation 3)}$$

3 Results

3.1 Total urban green space

The total UGS area for Sarajevo was 62.1 km^2, which was obtained via unsupervised classification based on Sentinel-2A satellite images; this value is roughly similar to the 58.5 km^2 found via manual UGS vectorization. The municipality of Novi Grad has the largest total UGS (i.e., 34.1 km^2), followed by the municipalities of Centar and Stari Grad (10.9 km^2 and 9.2 km^2, respectively), and the municipality of Novo Sarajevo has the smallest UGS area (4.2 km^2). The difference between the total UGS area and the built-up and other grey areas, obtained by unsupervised classification of the Sentinel-2 satellite images and manual mapping, is approximately 6% because of differences in spatial resolution. Differences are noticeable at polygon boundaries with preserved main information about the areas (Figure 2). Continuous green spaces are present in hilly and mountainous areas of the city, whereas more built-up zones are present in the flat topographic units.

3.2 Urban green space classification

Based on the results of the manual vectorization of UGSs, twenty-one classes of UGS in Sarajevo were identified. The spatial distribution of the UGS classes is the opposite of that of all white areas, where there is little or practically no greenery (Figure 3). These are the most densely built-up areas.

Public UGSs account for 8.79 km^2 (15.0%) of the total UGS area in Sarajevo (Table 3). Limited-access spaces, with a total of 49.05 km^2 (83.9%), comprise the largest part of the total UGS. UGSs with special purposes account for the smallest share: 0.66 km^2 or 1.1%.

Forest parks (10.1%), green spaces around apartment buildings (3.1%), and large parks (0.6%) comprise the largest share of public UGS in Sarajevo. Agricultural land (42.4%), urban forests (23.9%), and green spaces around houses (12.3%) are the most common types of limited-access UGS in Sarajevo.

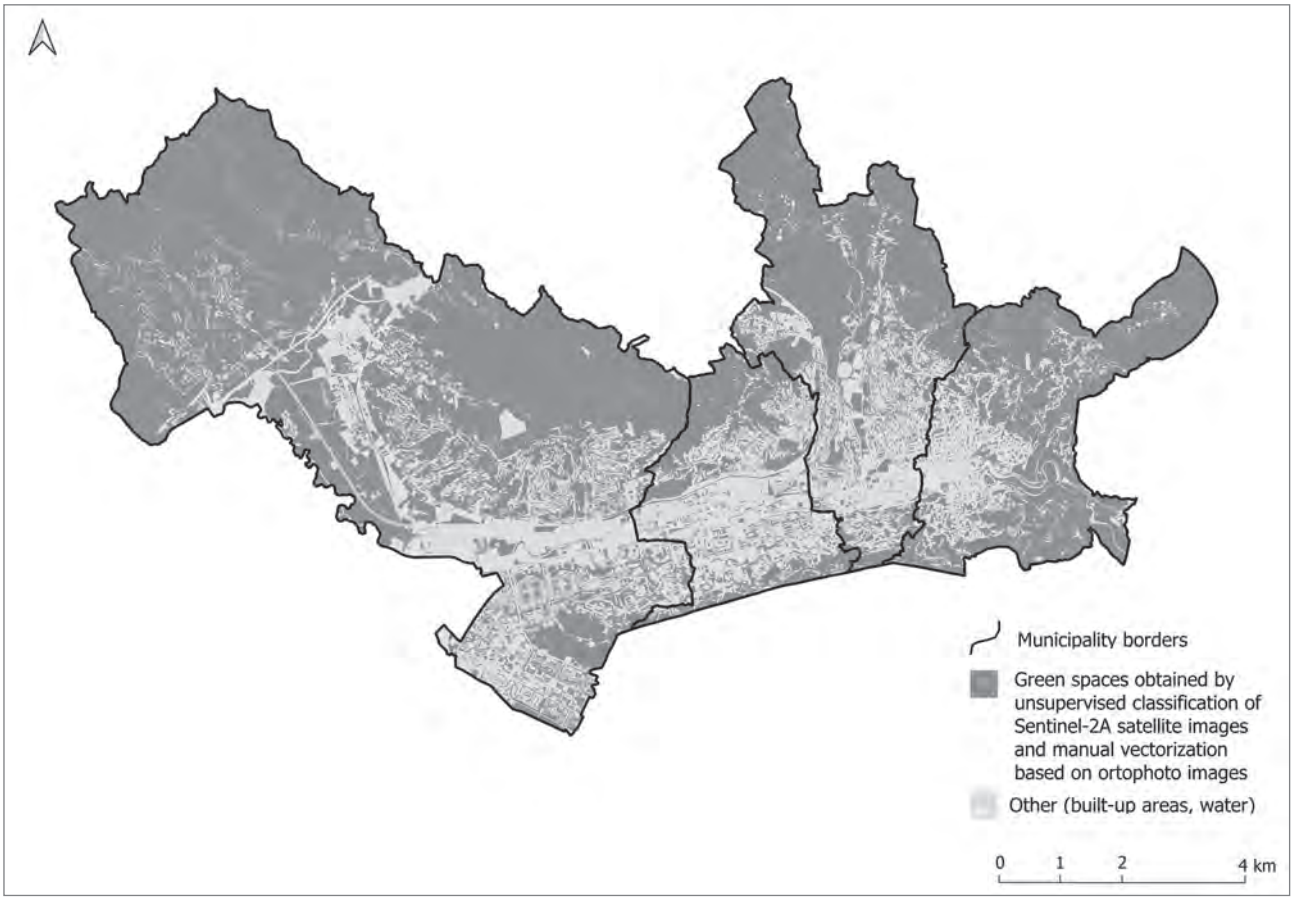

Figure 2: Spatial distribution of green (UGS) and grey areas in Sarajevo obtained by unsupervised classification of Sentinel-2A satellite images and visual interpretation and manual vectorization based on orthophoto images (illustration: authors).

Forest parks have the largest share of public UGS in all municipalities; they are usually located on the periphery of the research area and are less accessible to many residents of the city centre. Green spaces around apartment buildings rank second in terms of the share of public UGS. Parks are found only in the municipalities of Centar and Novo Sarajevo, where they account for 2.56% and 1.15%, respectively, of the total green space. The structure of UGSs with limited access differs with regard to municipalities. In the municipalities of Stari Grad, Centar, and Novi Grad, the most common classes are agricultural land, urban forests, and green spaces around individual houses, whereas in the municipality of Novo Sarajevo the most common classes are agricultural land, green spaces around houses, and green spaces around educational facilities.

3.3 Green space indicators

The share of green space based on manual vectorization in Sarajevo is 64.2%. This result is roughly similar to the value obtained by the unsupervised classification of satellite images, where the share of green space is 70.4% (Table 4).

The total UGS is 203.6 m^2 per capita in the urban area of Sarajevo. The indicators have different values with respect to the city area (Table 4). However, most municipalities have similar shares, ranging between 68% and 72%, and the total UGS per capita ranges between 207.0 and 277.8 m^2. Only the municipality of Novo Sarajevo has substantially lower values of the UGS share and the total UGS per capita: 45.6% and 65.7 m^2, respectively.

The obtained value of the public UGS per capita is 28.0 m^2 for the area of Sarajevo. Two municipalities, Novi Grad and Centar, have higher values of 42.8 and 33.8 m^2 per capita, respectively, and the other two municipalities, Stari Grad and Novo Sarajevo, have lower values of 16.8 and 18.6 m^2 per capita, respectively. When assessing the public UGS per capita, if forest parks, which are usually located on the periphery of urban areas, are excluded, the total public UGS per capita is 9.8 m^2 for Sarajevo. The lowest result is obtained for the municipality of Stari Grad, at only 1.4 m^2 per capita.

Because public green spaces provide the most social functions and are usually available to a large number of urban residents within a short distance, quantitative UGS indicators are pre-

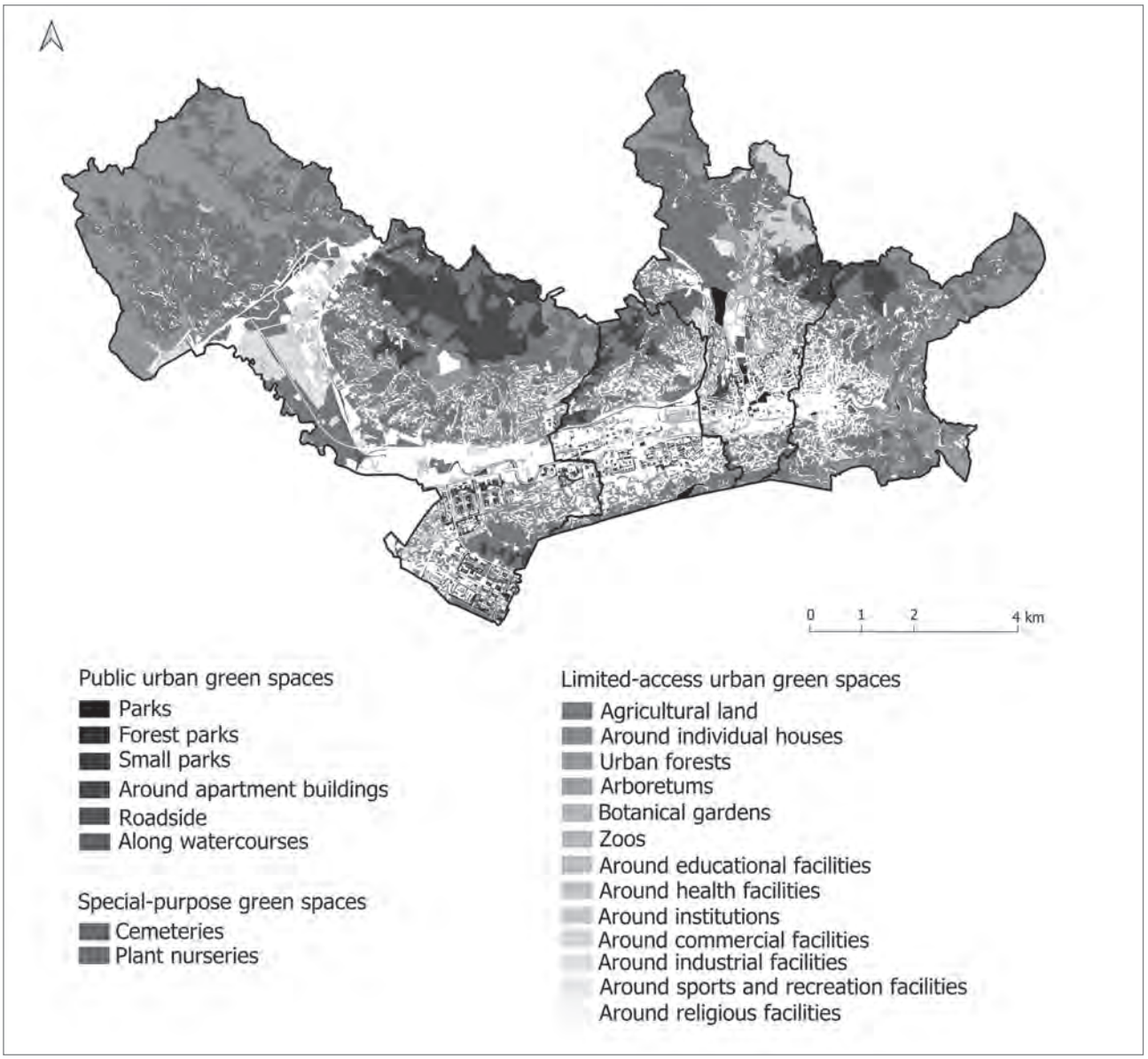

Figure 3: UGS classes in Sarajevo (municipalities of Novi Grad, Novo Sarajevo, Centar, and Stari Grad (illustration: authors).

Table 3: Areas of UGS classes and class shares by municipality and for Sarajevo (hectares).

UGSs		Stari Grad	Centar	Novo Sarajevo	Novi Grad	Sarajevo (total)
Public	Area	65.2	180.5	107.3	525.9	878.9
	Class abundance (%)	7.1	16.5	25.5	15.4	15.0
Limited-access	Area	837.3	874.6	312.0	2,881.3	4,905.1
	Class abundance (%)	90.7	79.9	74.1	84.5	83.9
Special-purpose	Area	20.9	39.9	1.6	3.7	66.0
	Class abundance (%)	2.3	3.6	0.4	0.1	1.1
Total	Area	923.4	1,095.0	420.9	3,410.8	5,850.0
	Class abundance (%)	100.0	100.0	100.0	100.0	100.0

Source: authors.

Table 4: Quantitative UGS indicators by municipality and for Sarajevo.

Municipality	Green space (%)	UGS per capita (m^2)		
		Total	Public	Public (excluding forest parks)
Stari Grad	71.4	263.7	18.6	1.4
Centar	67.7	207.0	33.8	19.1
Novo Sarajevo	45.6	65.7	16.8	7.6
Novi Grad	72.1	277.8	42.8	11.0
Sarajevo (total)	64.2	203.6	28.0	9.8

Source: authors.

Table 5: Public UGS (m^2) per capita for selected UGS classes by municipality.

UGS class	Municipality			
	Stari Grad	Centar	Novo Sarajevo	Novi Grad
Large parks	0	5.3	0.8	0
Small parks	0.6	0.7	1.1	1.1
Forest parks	17.2	14.8	9.2	31.9
Around apartment buildings	0	12.3	4.6	6.9

Source: authors.

sented for the following UGS classes: large parks, forest parks, small parks, and green spaces around apartment buildings (Table 5).

4 Discussion

4.1 Green space indicators

Regarding the intensity of the decrease in area of green spaces, applying the UGS standards approach is an effective measure for preserving these spaces. The obtained UGS indicator of 28 m^2 per capita for Sarajevo indicates an insufficient optimal UGS area. It also shows that the established goal of 47.9 m^2 per capita (Urbanistički, Sl. N. GS, no. 7/86) was not met. As an optimal value of UGS, 50 m^2 per capita is proposed by the World Health Organization (World Health Organization, 2012). This value is considered the most favourable for the general health of the population (Morar et al., 2014).

The spatial accessibility of UGSs is crucial for maximizing the overall benefits that these areas offer to communities. Based on this study, only 9.8 m^2 is regarded as more easily accessible to residents because most forest parks are found on the slopes of the city. Although UGSs fulfil essential ecological functions, their sociological impact can diminish if they are not spatially accessible to a large share of the population. Differences in the accessibility of UGSs can reflect broader socioeconomic inequalities in urban areas, particularly in low-income neighbourhoods that typically have fewer UGSs, leading to worsening social disparities (Dai, 2011). Furthermore, limited accessibility of UGSs can result in decreased physical activity among the population, contributing to a sedentary lifestyle and associated health problems, such as obesity and cardiovascular diseases (Giles-Corti et al., 2005; de Jalón et al., 2021).

Based on the calculated indicators, relative to the recommended UGS standards (Herzele & Wiedemann, 2003), this study indicates necessary limitations in the expansion of construction land for a sustainable urban environment. According to the 1986 spatial plan (Urbanistički, Sl. N. GS, no. 7/86), a scarcity of green areas can be observed. Over time, these areas are characterized by unsustainable urban development and have become increasingly less common in Sarajevo. However, the city is surrounded by natural forest areas; these contribute to the correction of UGS standard values, which should be evaluated.

4.2 Minimum functional green public space per capita

The results indicate that the total share of green space per capita is 64.2% (or 203.6 m^2 per capita), which is satisfactory for Sarajevo. The average share of total green infrastructure for thirty-eight European capital cities is 42% (European Environmental Agency, 2022), and Maes et al. (2019) estimated that the average cover of core cities in Europe with UGSs is 40%. The estimated value according to the study of the European Environmental Agency (2022) for Sarajevo is 46%. The differences between the results are likely primarily attributable to

the fact that not all types of green spaces were included, as in this study. A clear spatial pattern of UGS quantity can be seen in Europe: the lowest UGS provision occurs in southern and eastern Europe, increasing toward the north and northwest (Fuller & Gatson, 2009; Maes et al., 2019; European Environmental Agency, 2022). The reason for the relatively high share of UGS in Sarajevo is that, in places, the urban part of the city includes less built-up peripheral areas with larger agricultural areas and forested land, especially the urban part of the municipality of Novi Grad. These areas are mostly functionally limited in terms of providing multiple direct benefits for the population and are not accessible to a large number of residents. However, they possess very important habitat, regulating, and/or provisioning ecosystem functions. Thus, it is important to consider the quantity of functional public UGSs that provide the broadest range of benefits, focusing on their preservation and improvement, primarily by establishing a minimum public UGS per capita.

Our results show that the share of public UGSs in the total area for Sarajevo is 10.2%, whereas the estimated share according to the European Environmental Agency (2022) is 5%. The estimated total public green space per capita at the municipal level also shows an expected inconsistency. Some municipalities have higher UGS values (Novi Grad and Centar), whereas others have lower ones (Stari Grad and Novo Sarajevo). This depends on their functional role in the structure and historical development of the city. Therefore, it is important to consider the variability of urban environments in establishing UGS standards, given that certain neighbourhoods have specific urban characteristics and needs.

In a study of the mid-term and long-term development of communal activities in the city focusing on urban greenery, optimal per capita norms were proposed for the following UGS classes: 8 m^2 for large parks, 4 m^2 for small parks, 100 m^2 for forest parks, and 8 m^2 for green spaces around apartment buildings. Based on the results of green space indicators for the entire urban area of Sarajevo, it can be concluded that the optimal values proposed are not met in any of these classes. The results for Sarajevo as a whole were as follows: large parks (1.2 m^2 per capita), small parks (1.0 m^2 per capita), forest parks (21.4 m^2 per capita), and green spaces around apartment buildings (6.5 m^2 per capita).

Based on the results obtained from this analysis, Sarajevo has the potential to develop into a sustainable green-blue city. However, because the most densely populated parts of the city have the least amount of green space and because the spatial accessibility of UGSs that would satisfy the population's minimal needs is questionable, it is necessary to work on amending the current urban planning laws and on prescribing standards for UGS to ensure a sufficient quantity of UGSs. Urban planning guidelines specifically focused on UGSs should be developed and integrated into spatial planning, ensuring the preservation of existing urban green infrastructure and requiring investors to incorporate a sufficient percentage of green space in new projects. Public UGSs should be safeguarded through legal measures and formally recognized as public goods to prevent their conversion into built-up areas (Ballian et al., 2021). It is essential that guidelines adhere to a minimum standard of 9 m^2 of public UGS per capita. In peripheral parts of the city, where more land is available, the focus should shift toward achieving an optimal standard of public UGS per capita, tailored to the specific needs of different neighbourhoods, taking into account factors such as population density and the existing quality of UGSs. Given Sarajevo's unique topography, it is crucial that changes in spatial planning documents prioritize the protection of high-value agricultural land, urban forests, and forest parks. Agricultural land serves as a critical ecological buffer, offering essential services such as soil conservation and food production. These areas are particularly valuable in peripheral zones on sloped terrain, where they also aid in stormwater management and soil erosion control. Urban forests and forest parks, located primarily on the city's outskirts, help maintain ecological connectivity between urban and rural environments, while also contributing to stormwater management and soil stabilization. Linear green spaces, such as tree-lined streets and UGSs along watercourses, are often overlooked but are a crucial component of urban green infrastructure. These spaces are typically not well defined in higher-order spatial planning documents but are essential for creating continuous networks of green corridors that connect disparate green spaces across the city. In addition to providing recreational paths, these spaces serve as vital connectors for biodiversity, urban cooling, and improving air quality and ventilation. Given the limited opportunities for new larger UGSs in Sarajevo's central, highly built-up areas, it is important to preserve and expand existing linear green spaces and introduce alternative forms of urban greenery. Finally, involving the public in planning processes, surveys, and focus groups would contribute to improving UGSs that resonate with the preferences and needs of local populations, ensuring that UGS standards reflect community values.

4.3 Methodological approach, applicability, and relevance

This study makes some important contributions to understanding UGSs in Bosnia and Herzegovina because it provides basic information about the quantity, spatial arrangement, and classes of UGSs; as such, it is the first known research of this type and scope at the level of Sarajevo and the individual

municipalities within the city. In terms of spatial and thematic detail, it exceeds the data available in the Urban Atlas project and other geospatial data about UGSs in Sarajevo. More precise planning decisions require higher-resolution input data. The proposed approach combines automatic recognition of green and nongreen areas derived from Sentinel-2A data and more detailed manual vectorization and classification of UGSs based on higher resolution orthophotos. Therefore, the methodological approach in this article is applicable to all urban areas in Europe. The spatial information obtained using these methods has the potential for ongoing and easy modifications over time. The findings of this study will help in better understanding UGSs in Sarajevo and can serve as a reference for decisionmakers and policymakers for spatial planning and the general management of urban space in landscape architecture, for the recommendation of UGS norms in future spatial plans, for the preservation and improvement of existing UGSs, and for the protection of valuable ecosystem services. Furthermore, the results provide a basis for future research in this field and can provide better insight into the condition, quality, and significance of UGSs, spatial accessibility, and the ecosystem services that UGSs provide to improve their management. It is recommended that the study be extended to other municipalities in the Sarajevo Canton, considering the level of urbanization and the potential for improving urban green infrastructure, as well as other larger urban areas in Bosnia and Herzegovina, to gain insight into the state of UGSs and generate a basis for planning and managing greenery in accordance with sustainable city development.

4.4 Limitations

Although this study offers significant insights, there are limitations that may affect the accuracy of its findings. The temporal gap between the study period and orthophoto images may result in discrepancies in UGS vectorization, although additional geospatial data, including Google Hybrid data, together with the geospatial data available at the government website Geoportal.ba, served to partially address this challenge. Second, the UGSs classification methodology was based on integrating geospatial data with in-depth knowledge of the urban area, without complementary methods such as on-site visits. This may result in UGS classification inaccuracies. Future research should aim to utilize more current geospatial data and explore advanced classification methods to mitigate these limitations, improving the accuracy and applicability of the results.

5 Conclusion

Because official data on the urban area are not known, this study provides reliable information on the categories of urban green spaces in Sarajevo. In addition, based on the indicators of green spaces, it is possible to evaluate the quality of urban space by comparing it with known standards. The total public urban green space per capita was 28.0 m^2, or 9.8 m^2 if forest parks were excluded. The quantitative standards were not met with regard to the recommended optimal standards proposed in 1985 for Sarajevo or the optimal standard of 50 m^2 per capita recommended by the World Health Organization. The findings presented will help in better understanding urban green spaces in Sarajevo and serve as a reference for decisionmakers and policymakers for spatial planning and the preservation and improvement of existing spaces.

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