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Research Article

Temporal Changes in Urban Green Space Area and Per Capita Using GIS: A Case Study of Bojnurd City, North Khorasan Province, Iran

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ABSTRACT

Green spaces are essential for sustaining both natural and human life in urban areas. Their absence can disrupt well-being, harm air quality, mental health, and biodiversity, and reduce overall quality of life. Maintaining and expanding these spaces is crucial for the resilience and sustainability of cities. The present study aims to analyze urban green space changes and per capita urban green space in Bojnurd, North Khorasan Province. This study examines Bojnurd's per capita green space changes and the impact of the Urban Area Comprehensive Plan (UACP). To achieve these goals, green space areas were extracted using Landsat and Google Earth satellite images for the years 2006, 2013, and 2022. Furthermore, per capita urban green space was analyzed using demographic information and the area of green spaces at both the city level and within each of the two districts of Bojnurd municipality. The results indicate that per capita urban green space increased from 2006 (4.5 m²) to 2022 (5.59 m²), with both municipal districts showing growth, although Region One experienced a greater increase compared to Region Two. Implementing the UACP could further raise per capita green space to 9.81 m², thereby enhancing ecological balance and quality of life. A practical recommendation is to prioritize UACP implementation alongside the development of public green spaces. These findings provide a roadmap for urban planners to integrate green space development with demographic needs and urban policies. Prioritizing UACP execution and public green space expansion could contribute to creating more resilient and livable cities.

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1. INTRODUCTION

1.1 Background

Cities, as hubs of human activity and life, must rely on the structure and functions of natural systems to ensure their sustainability. The increasing physical expansion of cities leads to changes in land cover and a reduction in the cohesion of green infrastructure (Nasehi et al., 2022). Urban green spaces are among the most fundamental factors for the sustainability of both natural and human life in modern urbanization, and their absence can result in serious disruptions to urban life (Haq, 2011). From an environmental perspective, urban green spaces provide numerous ecological services, such as carbon sequestration, greenhouse gas absorption, mitigation of climate change effects (e.g., storms and runoff), oxygen production, noise reduction, urban health promotion, biodiversity preservation, and water retention (Heidt and Neef, 2008; Sayahnia et al., 2017; Hassanpour et al., 2020). The development of urban green spaces should align with community needs, taking into account any associated limitations (Haaland and van Den Bosch, 2015). Proper urban green space planning is vital to meet current and future needs as urbanization accelerates and the demand for a connection to nature grows (Kabisch et al., 2015). Fundamental changes in the relationship between humans and nature in urban settings underscore the importance of employing effective green space strategies in urban planning (Aronson et al., 2017). The study of urban green space changes, particularly their impact on factors like reducing urban heat islands, controlling runoff, and improving citizens' access to a better environment, can be evaluated across various spatial scales over time (Zhang et al., 2015; Gunawardena et al., 2017). Green spaces, designed with multiple functions for public use, include international, national (memorials, historical sites, military), forested (natural and artificial), botanical, commercial, industrial, recreational, urban (neighborhood, district, regional), green belts, plazas, and green refuges. Monitoring urban green space and per capita green space is crucial for sustainable city planning. It provides insights into whether the population has adequate access to parks and recreational areas, directly affecting public health and well-being. Tracking these changes helps identify spatial inequalities between districts and informs policymakers about areas needing intervention. Moreover, maintaining sufficient

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green space per capita contributes to ecological balance, air quality improvement, and urban resilience against environmental stresses. Regular monitoring allows for evidence-based urban development decisions and ensures that future growth aligns with both environmental and social sustainability goals.

1.2 Functions of Urban Green Spaces

Urban green spaces serve various roles and functions, including social-psychological, ecological, environmental, aesthetic, and economic functions (Van Leeuwen et al., 2010).

Social-Psychological Function: The urban green spaces play a significant role in meeting the social and psychological needs of citizens, strengthening social cohesion, and fostering connections with nature, all of which require thoughtful planning and design. With growing populations and urban industrialization, green spaces are increasingly vital for creating vibrant, memorable cities, offering relaxation, leisure, social interaction, stress relief, natural beauty, and a sense of peace and comfort (Finlay et al., 2015). Access to urban green spaces supports increased physical activity, improves public and social health, and fosters overall well-being. Studies show that limited access to green spaces is associated with higher rates of obesity and overweight, negative perceptions of personal health, and increased mortality risk (Dai, 2011).

Ecological Functions of Green Spaces: Urban green spaces play a vital role in preserving biodiversity and regulating the city's climate (Lepczyk et al., 2017 2000). Given that metropolitan areas are often classified as ecologically unstable, green spaces act as an effective countermeasure against ecological instability. The benefits of urban green spaces include reducing ambient temperature, increasing water infiltration, maintaining urban climatic balance, and preserving soil conditions.

Environmental Functions of Green Spaces: Urban green spaces improve the quality of urban life by mitigating the adverse effects of industrial expansion, making cities more meaningful as human habitats. Their benefits extend beyond city boundaries, enhancing neighboring areas by increasing land value, improving access to natural light, reducing noise pollution, and mitigating urban heat islands (Irvine, et al., 2009). Urban green spaces must correspond to the city's physical size, community needs, and future growth trends to sustain their environmental functionality. They contribute to air pollutant absorption, climate stabilization, temperature moderation, soil erosion control, urban runoff management, noise reduction, and wildlife habitat provision (Hashemi et al., 2009). Climate change, including rising temperatures, reduced rainfall, and more frequent heatwaves, imposes significant stress on urban environments, affecting both human health and ecosystem functions. Urban green spaces play a crucial role in mitigating these impacts by providing shade, increasing evapotranspiration, and cooling the surrounding areas, thereby reducing the urban heat island effect. They also improve air quality by absorbing pollutants and greenhouse gases and help manage stormwater runoff during heavy rainfall events. Moreover, green spaces sustain urban biodiversity and support ecosystem resilience, contributing to overall environmental sustainability. In addition, they enhance mental health, social well-being, and recreational opportunities for residents. Proper planning and expansion of urban green areas make cities more adaptable and resilient to the effects of climate change. Overall, green spaces represent an essential strategy for sustainable and climate-resilient urban development.

Aesthetic Functions of Green Spaces: The livability and attractiveness of urban environments owe much to the aesthetic contributions of green spaces. Green space design, as an integral part of urban planning, enhances city landscapes, including highways, land-use separation, and other urban design elements. Implementing aesthetically pleasing landscapes through green space projects fosters a sense of well-being and joy among citizens (Wang et al., 2019).

Economic Functions of Green Spaces: Urban green spaces contribute economically by attracting tourists, stimulating commerce, increasing land and property values, and generating higher municipal tax revenues (Hashemi et al., 2009).

1.3 Importance of per capita green space

The terms green space ratio, green space coverage, and per capita green space represent the quantity of available green spaces, with per capita green space indicating the allocation of green space per individual, which decreases as population size increases. Social green spaces, or those open to public access without restrictions, are particularly significant. The concept of per capita green space is especially relevant to areas designed for leisure, recreation, and play (Addas, 2022). The quantity and per capita availability of urban green spaces, public parks, and recreational areas positively influence the environmental, economic, and social dimensions of urban livability, attractiveness, and sustainability (Chiesura, 2004). According to studies conducted by Iran's Ministry of Housing and Urban Development, the standard and acceptable per capita green space in Iranian cities ranges from 7 to 12 square meters per person (Beiranvand et al., 2013). In contrast, the United Nations Environment Programme recommends a per capita green space of 20 to 25 square meters (Teimouri and Yigitcanlar, 2018). Variations in per capita green space between cities arise from differing geographical and climatic conditions, with specific urban development plans determining the actual figures (Lin et al., 2019).

1.4 Literature review

Shalaby and Tateishi (2007) analyzed coastal land use and cover changes in Egypt using TM images from 1987 and ETM images from 2001. They reported significant land cover changes due to tourism and agricultural development projects, which reduced vegetation cover. Rafiee et al. (2009) examined green space changes in Mashhad using satellite imagery and landscape metrics. Their findings revealed a significant decline in the extent of Mashhad's green spaces. They also demonstrated that combining satellite imagery with landscape metrics and vegetation indices could effectively assess human quality of life. Sha and Tian (2010) used landscape metrics and GIS to study the spatial-temporal characteristics of urban development in Phoenix, USA. Their analysis of agricultural, urban, desert, and reclaimed land classes demonstrated that landscape metrics are effective tools for identifying land use changes. Azizi et al. (2016) utilized remote sensing techniques with LANDSAT satellite data to map land use in Ardabil, Iran for 1989, 1998, 2009, and 2013. Their findings indicated that two-thirds of the study area, covering about 58,645 hectares, experienced changes between 1989 and 2009. The most significant changes occurred in agricultural and human-made land uses, both of which increased. The calculated kappa coefficient for assessing changes exceeded 0.8.

Badiu et al. (2016) assessed the use of urban green space (UGS) per capita as a sustainability target in Romanian cities. Their analysis of 38 cities revealed discrepancies between reported and actual UGS data, concluding that a uniform target of 26 m² per inhabitant is unrealistic and should instead be adapted to each city's unique characteristics. Anabestani et al. (2021) analyzed structural changes in the landscape and urban development patterns in Mashhad over a 20-year period (1999–2019) using multi-temporal Landsat imagery. They found that built-up areas experienced the most significant spatial changes, increasing in size, while agricultural land and orchards sharply declined between 2009 and 2019. Barren land decreased, and rangelands remained relatively stable during this period. Chen et al. (2023) examined the relationship between urban form and green space equity in 147 shrinking cities in Japan. They found that urban shrinkage, population compactness, and patch continuity influence green space distribution, with compact cities supporting more equitable development.

According to the literature, despite the growing body of research on green space assessment, tracking specific changes in per capita green space over time—particularly in urban contexts—remains crucial across cities with varying conditions. Further investigation is needed to measure how per capita green space evolves over time and to better understand its impact on urban sustainability. Most existing studies focus on large cities, with limited attention to long-term changes and district-level disparities in smaller cities such as Bojnurd. This study examines historical trends and future projections of per capita green space to address this gap.

1.5 Scope and objective

Developing urban green spaces is key to enhancing social life and sustainability by improving their quality, creating new areas, providing amenities for all ages, and ensuring accessibility (Tian et al., 2011). Changes in urban green spaces and their distribution can be influenced by various factors, including citizen demand, available space, land ownership, per capita green space, and urban development project plan (Sun et al., 2019).

Bojnurd, the capital of North Khorasan Province, has experienced significant urban growth since becoming the provincial center in 2005. Bojnurd was chosen for this study due to its rapid urbanization and the need to assess changes in urban green spaces over time. As the provincial capital, the city is undergoing rapid development, directly affecting the availability and quality of its green spaces. This expansion has led to the conversion of agricultural land into urban areas, characterized by dispersed sprawl into surrounding regions. It has also resulted in socio-spatial segregation, with some ethnic groups experiencing inequality at the neighborhood level.

Unlike earlier studies, this research examines the temporal dynamics of per capita green space in Bojnurd at both the city and district scales by integrating GIS-based analysis with demographic data and evaluating future conditions under the Urban Area Comprehensive Plan (UACP).

The findings aim to guide urban planners, municipal authorities, and policymakers in improving the allocation, expansion, and management of green spaces in Bojnurd. Landscape architects can apply the results to design multifunctional and accessible green areas, while local communities benefit from improved environmental quality, recreation, and well-being. By identifying district-level disparities and potential improvements under the UACP, the study supports more equitable and sustainable urban development.

This study aims to evaluate changes in green space in Bojnurd over a 30-year period. Furthermore, it will analyze historical changes in urban per capita green space using maps from Bojnurd's Urban Area Comprehensive Plan (UACP).

2. STUDY AREA

Bojnurd County, located in North Khorasan Province, is bordered to the north by Turkmenistan, to the west by the counties of Raz and Jargalan, Atrak, Ashkhaneh, and Jajarm, to the south by Esfarayen County, and to the east by Shirvan County. The city of Bojnurd, serving as the administrative center of Bojnurd County, covers an area of approximately 3,200 hectares and, according to the 2016 census, has a population of about 235,000. Figure 1 illustrates the location of Bojnurd within North Khorasan Province and Iran.

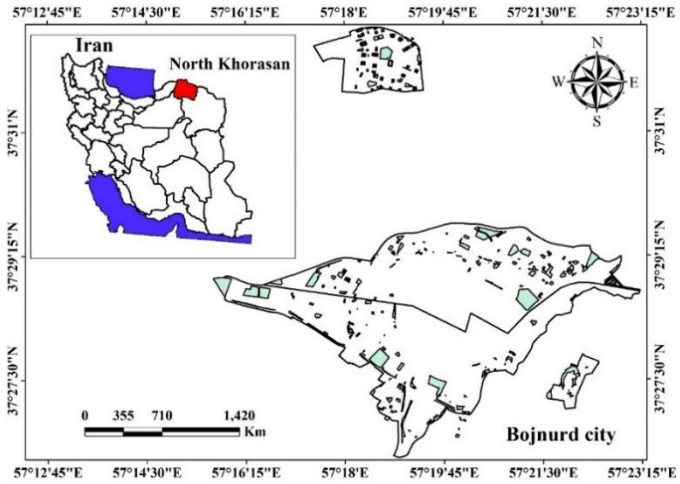


Figure 1. Location of Bojnurd city and its two municipal districts in Iran.

3. METHOD

3.1 Data

The data and information required for the present study include the boundaries of the urban area and each of Bojnurd's municipal districts, population data for Bojnurd city based on the national census, and satellite images of the study area recorded by Google Earth. Necessary processing steps were applied to these data for subsequent stages of the study (Shahtahmassebi et al., 2021; Mostafazadeh et al., 2024). For this research, information regarding the urban boundary, municipal districts, and Urban Area Comprehensive Plan (UACP) maps of Bojnurd city was obtained from the Bojnurd Municipality.

Population data for Bojnurd city and its municipal districts were acquired from the Planning and Budget Organization of North Khorasan and the website of the Statistical Center of Iran. Maps derived from Landsat satellite images were downloaded and processed using Google Earth for the years under study, as summarized in Table 1 (Hamidi et al., 2016).

Table 1. Satellite Images Used for Examining the Spatial Distribution Pattern and Changes in Per Capita Urban Green Space in Bojnurd

No.	Satellite	Sensor	Date (Gregorian)
1	Landsat 5	TM	2006-09-04
2	Landsat 5	TM	2013-10-04
3	Landsat 8	OLI	2022-08-03

3.2 Determining urban green space areas

The boundaries of urban green spaces during the study period were identified using Landsat satellite images and Google Earth software (Hamidi et al., 2016). These images were selected for their reliable atmospheric and radiometric corrections, making them well-suited for the research objectives. In addition, minimal cloud cover was a key criterion in image selection. The identified urban green spaces included parks, public green areas, tree-covered streets, natural areas, and other green spaces within the urban limits for the years 2006, 2013, and 2022, based on maps generated from the satellite images and Google Earth (Alaei, et al., 2024; Bagheri et al., 2021). Green spaces within each municipal district of Bojnurd were also extracted for further comparative analysis across the study years. To validate the urban green space maps for Bojnurd, field surveys were conducted at over 50 random locations within different urban green space categories. These random points within the designated green space areas were selected using the Hawths Tools extension in the ArcGIS software environment (Latta et al., 2013).

3.3 Calculation and analysis of urban per capita green space

Urban green space can include parks, gardens, and other publicly accessible natural areas. Calculations of green space can be performed at various levels, such as city, district, or neighborhood. Per capita green space has a significant impact on public health, social well-being, and environmental sustainability. Studies have shown that green spaces can reduce stress, improve mental health, and promote physical activity. Furthermore, green spaces contribute to mitigating the effects of climate change and improving urban air quality (WHO, 2016). The accuracy of per capita green space calculations is influenced by factors such as the definition of urban green space, data quality and accessibility, area size and shape, population data accuracy, and the inclusion of private green spaces. Therefore, special attention should be paid to these aspects when calculating per capita green space to confidently interpret the results. Proposed per capita urban green space values vary significantly across different sources (Table 2), indicating that per capita green space is relative and lacks universally accepted standards. However, the quality and functionality of green spaces are generally considered more important than their quantity and extent.

Demographic data for the study area and the different municipal districts of Bojnurd for the years 2006, 2012, and 2022 were obtained from the Organization for Management and Planning of North Khorasan Province and Bojnurd Municipality. These data were used to calculate per capita green space in Bojnurd during the study years (https://amar.org.ir/en).

The calculation of urban per capita green space is considered an essential indicator for assessing the quality of urban environments. Per capita green space is defined as the amount of green space available per person in a specific area. Urban per capita green space is calculated by dividing the total area of green space by the population of the region (Shen et al.,, 2017). Finally, changes in urban per capita green space during the study period in Bojnurd were analyzed and compared across different municipal districts.

ArcGIS and Google Earth were used to extract and process Landsat images. Urban per capita green space was calculated using demographic data and urban boundaries in ArcGIS. Field validation and random point selection were conducted using the Hawths Tools extension. Data analysis and visualization were performed in Excel. These tools enabled an accurate assessment of temporal and spatial changes in green space and per capita availability.

4. RESULTS AND DISCUSSION

4.1 Urban green spaces of the study area

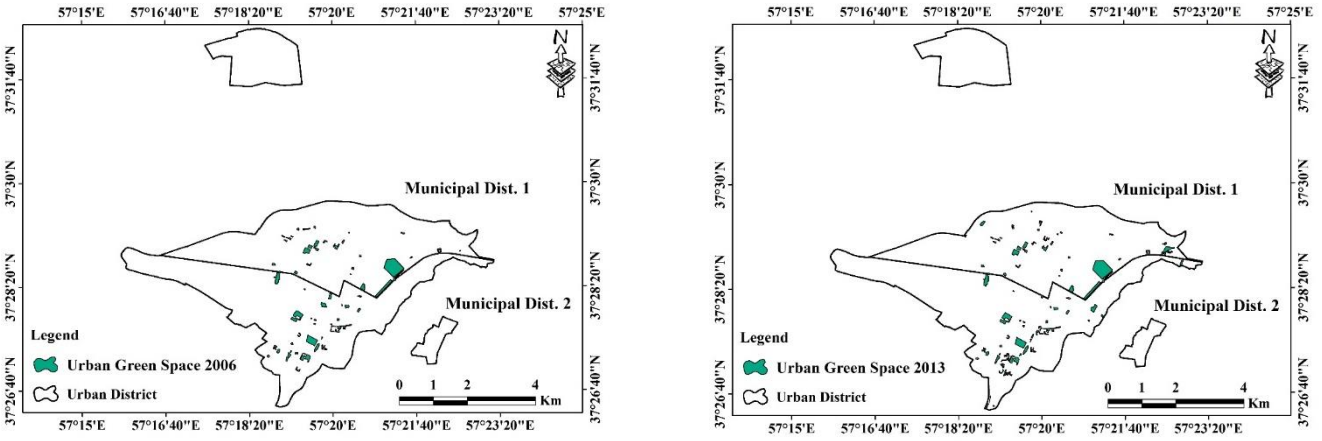
The results of urban green space mapping for Bojnurd for the years 2006 and 2013 are shown in Figure 2, while the results for 2022 and under the Urban Area Comprehensive Plan (UACP) for Bojnurd are presented in Figure 3.

The total area of urban green spaces in Bojnurd over the study period was as follows: 70.14 hectares in 2006, increasing to 81.11 hectares in 2013, and further growing to 129.86 hectares by 2022. Under the Urban Area Comprehensive Plan (UACP), the area is projected to reach 227.92 hectares.

Figure 4 and 5 illustrate views of urban green spaces that are among the high-traffic areas in various parts of Bojnurd city. These parks, due to their location within the urban boundary, are particularly important for social and recreational functions.

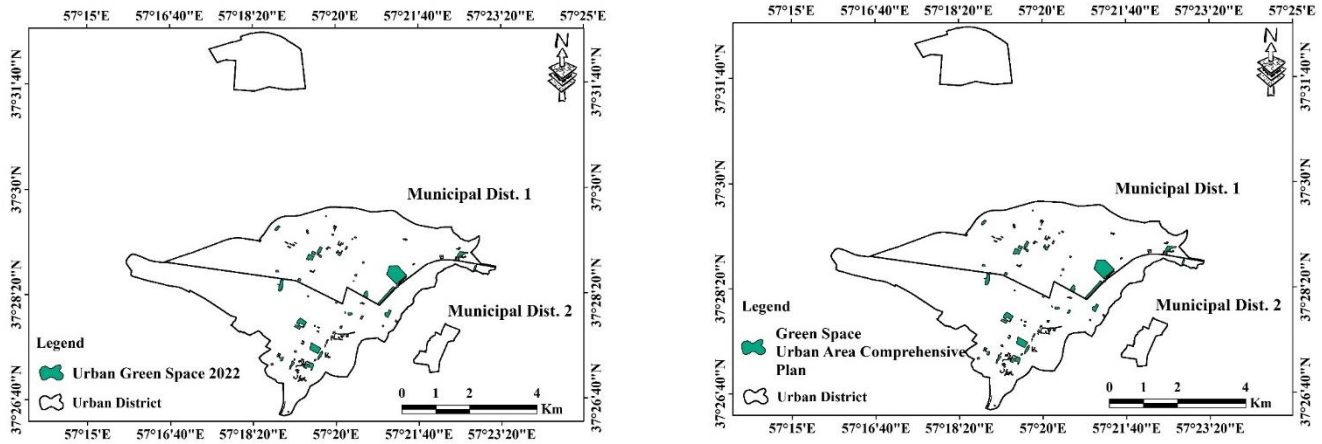
Table 2. Recommended Per Capita Urban Green Space by Various Iranian Authorities

Authority	Recommended per capita green space (m^2)
Ministry of Housing and Urban Development	7 to 12
National Organization of Municipalities and Rural Affairs	20
Plan and Budget Organization (Urban Green Space Design Standards)	12 to 40
Department of Environment (Expert elicitation)	30 to 50
Tehran Municipality Parks and Green Spaces Organization	25 to 50
Comprehensive Plan for Sorkheh Hesar and Khojir National Parks	15 to 50
Russian Consulting Engineers for Puladshahr City	25
Atak Consulting Engineers for Tehran City	10 to 35
A.L.P. Consulting Engineers	21.75 to 29.75



(a) (b)

Figure 2. Urban Green Space Boundaries of Bojnurd for 2006 (a) and 2013 (b)



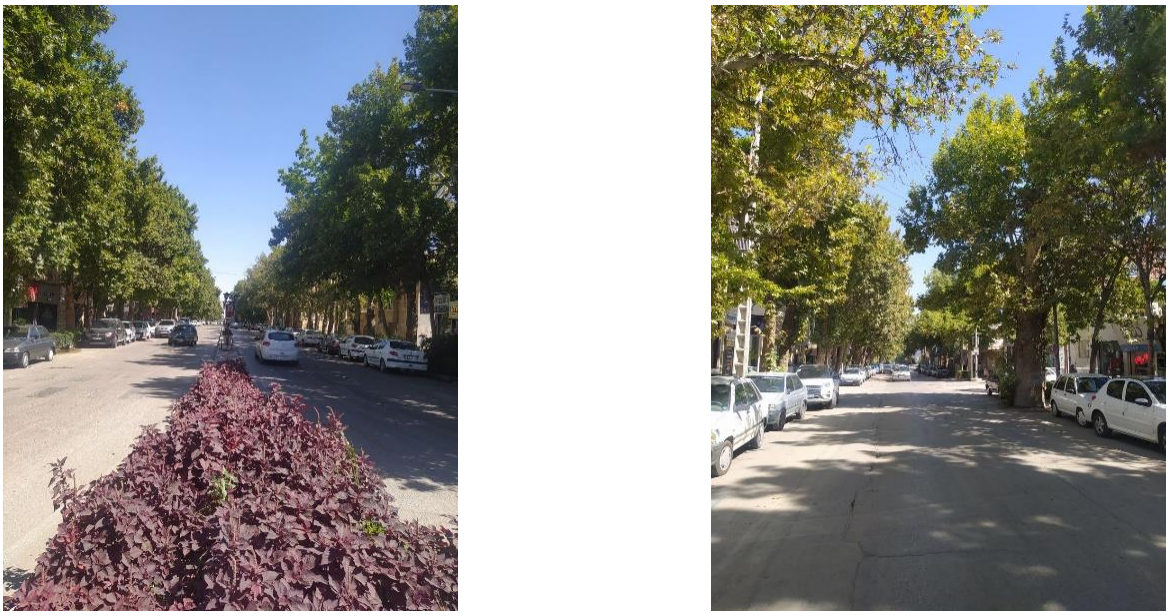
(a) (b)

Figure 3. Urban Green Space Boundaries for 2022 (a) and the Urban Area Comprehensive Plan (UACP) (b) of Bojnurd

(a) (b)

(c) (d)

Figure 4. Views of urban green spaces in Bojnurd (a: Afarinesh Park, b: Parke Shahr, c: Madar va Kodak Park, d: Shahre-bazi Park).



(a) (b)

Figure 5. Views of fringe green spaces, Nader Street (left) and Shariati Street (right) in Bojnurd.

4.2 Urban Per capita green space in Different Time Periods Across the Dual Municipal Districts

The results of urban per capita green space calculations for the study periods (2006, 2013, 2022) and under the Urban Area Comprehensive Plan (UACP) for Bojnurd, at both the city boundary and within each of the two municipal districts, are presented in Figure 6.

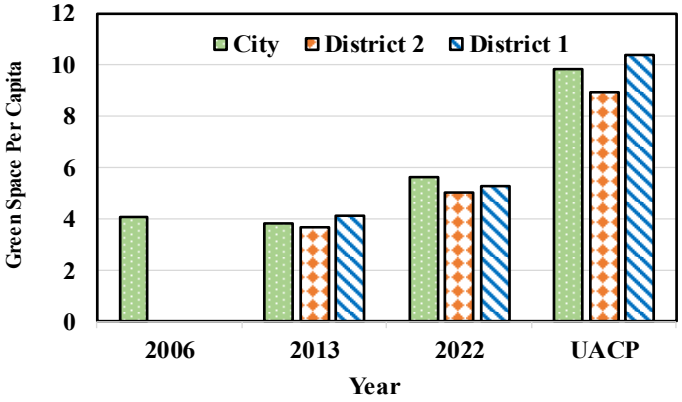


Figure 6. Per capita urban green space for each of the two districts during the study years and the Urban Area Comprehensive Plan (UACP) of Bojnurd city

The presence of parks and green spaces in a city acts as a filter that reduces environmental pollution, supports individual and social health, and provides environmental tranquility (Ezzatpanah et al., 2016). Urban per capita green space is one of the key indicators used to assess urban green space infrastructure (Badiu et al., 2016). According to studies conducted by the Ministry of Housing and Urban Development, the standard and acceptable urban per capita green space in Iranian cities ranges from 7 to 12 m², which is lower than the 20–25 m² recommended by the United Nations Environment Programme. However, these values vary across cities due to differences in geographical and climatic characteristics, with specific targets determined by approved urban plans.

Based on the results of calculating urban per capita green space in Bojnurd during the study period, it can be stated that per capita green space in the city and its two municipal districts increased from 2006 to 2022. Specifically, urban per capita green space in Bojnurd was 4.05 m² in 2006 and increased to 5.59 m² in 2022. Despite this growth, the calculated per capita green space still falls short of the national standard (12 m²). Analysis of the temporal trends shows a steady increase: 4.05 m² in 2006, 4.85 m² in 2013, and 5.59 m² in 2022, reflecting gradual expansion of green areas in the city. This upward trend is observed both at the city level and within the two municipal districts, with District 1 consistently exhibiting higher per capita values than District 2. These data demonstrate that urban planning initiatives and green space development have positively influenced the availability of green space per resident, highlighting the importance of strategic planning in enhancing urban livability and environmental quality.

The increase in urban green space and per capita observed in Bojnurd aligns with trends reported in other Iranian cities. Unlike Mashhad, where Rafiee et al. (2009) observed a decline in green spaces, Bojnurd shows a consistent increase from 2006 to 2022. Similarly, the growth in green space area mirrors patterns reported in Ardabil (Azizi et al., 2016), although Bojnurd's per capita remains below national standards. Compared to international findings, such as those in Romanian cities (Badiu et al., 2016) and Japanese shrinking cities (Chen et al., 2023), Bojnurd demonstrates moderate improvements, emphasizing the role of planned urban development. These comparisons highlight the effectiveness of local planning measures, such as the Urban Area Comprehensive Plan (UACP), in promoting green space expansion, while also indicating that disparities between districts remain an ongoing challenge. Overall, Bojnurd's trends confirm that integrating demographic considerations with urban planning is essential for sustainable green space development.

It should be noted that implementing the Urban Area Comprehensive Plan (UACP) in Bojnurd will significantly improve urban per capita green space. In addition, Dadashpoor and Jahanzad (2015) identified the lack of urban green space as a major issue in the country's urban development, based on comparisons of urban green space levels with standard values in many Iranian cities. Public green space is particularly important from a social environment perspective, as it refers to areas freely accessible to the general public. Consequently, the

concept of per capita green space applies only to those green spaces designated for leisure, play, and recreation. With full implementation of the UACP, urban per capita green space in Bojnurd is projected to reach 9.81 m².

The increase in Bojnurd's per capita green space, from 4.05 m² in 2006 to 5.59 m² in 2022, is consistent with trends observed in other Iranian cities (Rafiee et al., 2009; Anabestani et al., 2021) but remains below the national standard of 12 m² and international benchmarks of 20–25 m² (Teimouri and Yigitcanlar, 2018). These findings indicate spatial disparities between districts and provide guidance for implementing the UACP to expand multifunctional green spaces, enhance ecological balance, and improve urban sustainability.

Regarding urban per capita green space in Bojnurd's two municipal districts, it should be noted that the division into dual districts occurred after 2006; therefore, population and per capita green space values were not calculated for earlier years. In 2012, per capita green space was 4.08 m² in District 1 and 3.64 m² in District 2. By 2022, the values had increased to 5.26 m² in District 1 and 5.03 m² in District 2. With full implementation of the UACP, per capita green space is projected to reach 10.37 m² in District 1 and 8.93 m² in District 2. These results show that, although both districts remain below standard values, District 1 consistently has higher per capita green space than District 2, highlighting the need for targeted interventions by urban authorities to improve equity across the city.

Based on the study results, full implementation of the Urban Area Comprehensive Plan (UACP) should be prioritized to increase urban per capita green space toward national standards. Special attention is required to expand green spaces in areas with the lowest per capita, particularly District 2. Developing multifunctional green spaces with recreational, educational, and cultural facilities can enhance citizens' quality of life. Preserving and expanding peripheral and street green spaces can improve air quality and reduce pollution. Urban planning should align with population growth and demographic needs to ensure sustainable development. In addition, citizen participation in the design and maintenance of green spaces can strengthen social well-being and resilience. Incentive policies promoting investment in both public and private green spaces are recommended. These findings provide practical guidance for policymakers to develop more livable and environmentally resilient cities.

5. CONCLUSIONS

This study aimed to determine changes in urban green spaces and urban per capita green space during the study period, as well as under future urban development conditions defined by the Urban Area Comprehensive Plan (UACP) for Bojnurd. Based on the findings, the total area of urban green spaces in Bojnurd increased from 70.14 hectares to 129.86 hectares over the study period. Analysis of urban per capita green space at both the city level and within the two municipal districts indicates a steady increase, rising from 4.05 m² to 5.59 m². Furthermore, implementation of the UACP is projected to raise urban per capita green space to 9.81 m². The results highlight progress in urban greenery despite rapid urbanization. District 1 exhibited a greater per capita increase compared to District 2, revealing spatial disparities that require targeted interventions. The study demonstrates the potential of the UACP to enhance ecological balance and improve quality of life, providing a roadmap for urban planners to integrate green space development with demographic needs and urban policies. Prioritizing UACP implementation and public green space expansion could contribute to more resilient and livable cities. The study has some limitations. The quality and functionality of green spaces were not assessed; only their area and per capita values were considered. Additionally, projections of future urban development were based on the UACP, which may differ from actual implementation outcomes. Future research could focus on assessing the quality and multifunctionality of urban green spaces, beyond their area and per capita values. Scenario-based modeling of urban growth can help predict changes in per capita green space under different development plans. Further evaluation of spatial equity in green space distribution between districts is recommended. Integrating socio-environmental factors with green space planning could improve urban resilience. Finally, long-term monitoring using high-resolution satellite imagery would enhance understanding of urban greenery dynamics.

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