Multifunctional Evaluation of Urban Green Infrastructure for Combating Climate Change: A Case of Sancaktepe District in Istanbul Metropolitan City

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https://doi.org/10.29227/IM-2025-02-02-086

Submission date: *2025-05-29* | Review date: *2025-06-25*

Abstract

Urban areas worldwide are increasingly facing environmental challenges due to rapid urbanization and climate change. Phenomena such as urban heat islands (UHI), carbon emissions, and biodiversity loss significantly impact human health and urban livability. In response, Urban Green Infrastructure (UGI) has emerged as a key strategy, linking environmental sustainability with spatial planning to promote climate resilience and sustainable development. This study evaluates the multifunctional effectiveness of UGI in mitigating climate-related impacts in Sancaktepe, a rapidly urbanizing district in Istanbul that has developed informally over environmentally sensitive land. Despite these pressures, Sancaktepe demonstrates substantial UGI potential, as indicated by data from the Istanbul Green Area Management System (YAYSIS). The evaluation focuses on four main functions: UHI mitigation, biodiversity enhancement, ecological corridor potential, and carbon sequestration. Land Surface Temperature (LST) was used to assess UHI mitigation capacity, and results show that natural vegetative zones maintain significantly lower surface temperatures than plantation areas, emphasizing the cooling effect of mature green systems. Biodiversity assessment revealed that the district includes 224 plant taxa and 10 endemic species, primarily concentrated in the Ömerli Basin and Aydos Forest. These preserved regions also support six distinct habitat types and reflect the district's high ecological value. Carbon sequestration analysis indicates that plantation efforts across Sancaktepe's settlement areas contribute approximately 2,139,610 tons of carbon storage, although natural vegetation areas exhibit greater per-area sequestration capacity. A composite Urban Green Infrastructure Performance Index (UGI-PI) was developed to spatially synthesize these indicators using three parameters: Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), and Normalized Difference Built-up Index (NDBI). Each indicator was normalized, and the resulting index was classified into five performance categories using equal interval classification. The UGI-PI map reveals significant spatial variation: northern and eastern areas (including the Ömerli and Aydos zones) score very high in terms of UGI effectiveness, while central and southern urban neighborhoods score low due to high built-up intensity, reduced vegetation cover, and elevated surface temperatures. These low-performing areas are less effective under current conditions but may benefit from targeted small-scale interventions such as tree planting, vertical greening, and pocket parks. The integration of UGI-PI enhances the research by providing a spatial decision-support tool that identifies both conservation-priority zones and vulnerable areas requiring improvement. This framework not only evaluates the current performance of UGI systems but also contributes to strategic climate adaptation planning. The findings reinforce the need to protect natural vegetative zones while implementing targeted urban greening strategies in climate-stressed districts like Sancaktepe.

Keywords: *Urban Heat Island mitigation, Urban Green Infrastructure Performance Index, Ecological Corridors, Carbon Sequestration, Biodiversity, Sancaktepe.*

1. Introduction

The globe is facing the greatest urbanization and growth in population in recent history, which will drastically affect the quality of life for people, particularly those who live in urban areas and ecological resources (Pala et al., 2024). Urban expansion, compounded by climate change and phenomena like the urban heat island effect, negatively impacts human health and urban livability (Ramyar et al., 2021; Pala et al., 2024; Filho et al., 2019). As urban populations grow, the concept of Green Infrastructure (GI) has gained prominence in political agendas, connecting environmental sustainability, urban design, and governance (United Nations, 2016). GI has emerged as a vital strategy for

mitigating these challenges by enhancing urban resilience. It includes a range of interventions such as parks, green roofs, and urban forests that provide ecosystem services, promote biodiversity, and support climate adaptation and mitigation efforts. Globally, cities are increasingly adopting GI as part of sustainable urban planning to balance development with environmental stewardship (Hidalgo García, 2023).

The increasing attention given to GI is supported by recent policies and guidelines developed by cities and countries around the world, such as the Philadelphia Green Stormwater Infrastructure Planning Guidelines in the United States (Philadelphia Water, 2015), the Green Infrastructure Planning Action Guidance in England (UK Government, 2016), and in Türkiye, YAYSIS (Green Area Management System Strategy, n.d.). YAYSIS is a green area management strategy developed to support sustainable urban planning and maintain green infrastructure in Turkish cities, particularly in metropolitan areas such as Istanbul. It provides municipal authorities and planners with data, reports, and strategic recommendations for managing green spaces, enhancing biodiversity, and mitigating the urban heat island effect. As a rapidly urbanizing metropolis, Istanbul mirrors global trends in urban growth and its associated environmental pressures. For many years, Istanbul has experienced the transformation of forests, agricultural fields, and pastures into concrete developments (Pala et al., 2024; Norton et al., 2015). Impervious surfaces have expanded 1.5 times globally between 1990 and 2018, intensifying the urban heat island (UHI) effect, which is further exacerbated by rising heatwaves linked to climate change (Rocha et al., 2022). Building on this context, the present study investigates the multifunctional performance of Urban Green Infrastructure in Sancaktepe District, Istanbul, to determine its capacity to mitigate urban climate impacts and support sustainable development.

1.1. Bibliometric Trends in UGI Research

A bibliometric analysis was conducted using VOSviewer to explore evolving research trends in UGI. Figure 1 illustrates the frequency and co-occurrence of keywords in UGI-related studies, comparing literature before 2019 and after 2020. The results reveal a noticeable shift in focus from rural and ecosystem-based themes toward urban-scale concerns such as urban heat islands, carbon sequestration, and climate adaptation. In recent years, urban ecosystems have gained prominence in UGI literature, aligning with the increasing urgency of climate change and urban resilience. Keywords such as urban green infrastructure, urban heat island, and climate change show a marked increase in frequency after 2020. However, the analysis also highlights a gap: the integrated assessment of ecological corridors, biodiversity, carbon sequestration, and UHI mitigation in a unified UGI framework remains limited.

This observed gap reinforces the relevance of this study, which aims to develop a spatially integrated Urban Green Infrastructure Performance Index (UGI-PI) that combines these interrelated ecological functions. By bridging fragmented research themes, the study contributes to a more holistic approach in evaluating UGI performance in rapidly urbanizing contexts like Sancaktepe.

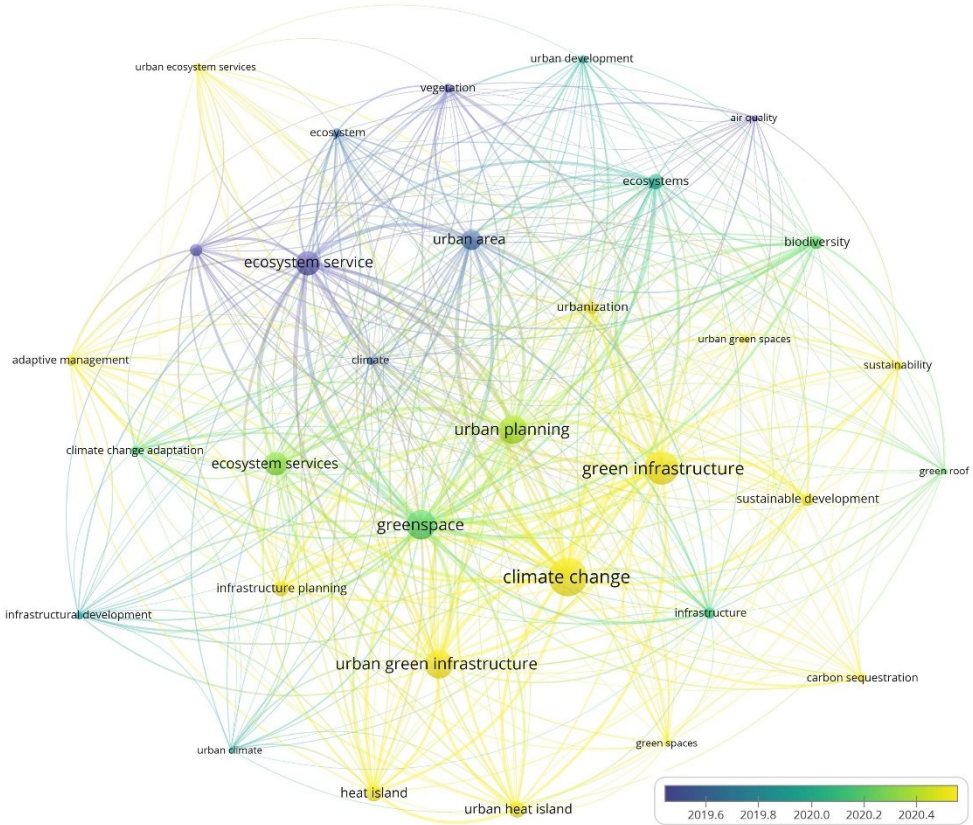

Fig. 1. Keyword frequency in UGI research before 2019 and after 2020, developed using VOSviewer

To quantify the multifunctionality of UGI and assess its effectiveness across different landscapes, this study introduces the Urban Green Infrastructure Performance Index (UGI-PI). This composite index integrates key biophysical indicators, including the Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), and the Normalized Difference Built-up Index (NDBI), to evaluate green infrastructure performance in a spatially explicit manner. By synthesizing these parameters, the UGI-PI offers a holistic view of how effectively UGI contributes to climate resilience and ecological sustainability in urban areas.

The multifunctional benefits of UGI in reducing UHI have been well documented. Studies by Hidalgo García (2023) and Norton et al. (2015) confirmed that UGI features like trees and green spaces significantly reduce LST. Priya and Senthil (2021) emphasized the cooling role of vegetation in tropical cities, while Grilo et al. (2020) reported temperature reductions up to 3°C in Mediterranean cities. Rocha et al. (2022) emphasized climate-resilient species selection for sustained cooling in Berlin, and Seletković et al. (2023)

demonstrated the cooling role of urban forests in Zagreb. Moreover, UGI supports ecosystem services such as air purification and biodiversity enhancement (Sebastiani et al., 2021; Arthur & Hack, 2022). Ecological corridors are another essential component of UGI. They support biodiversity and improve ecosystem services, particularly in urban areas facing flooding and heat stress (Zhang et al., 2024; Isola et al., 2024). By reconnecting fragmented habitats, these corridors enhance ecological stability and provide adaptive pathways for urban ecosystems. Connop et al. (2016) advocate for biodiversity-focused UGI designs, while Zhang et al. (2024) and Isola et al. (2024) further emphasize their role in building climate resilience. Istanbul's unique geography supports a rich range of ecosystems, including over 2,500 native plant species. However, ongoing urbanization, pollution, invasive species, and limited biodiversity integration into planning pose serious risks. Biodiversity is essential to maintaining ecosystem services and ensuring long-term sustainability (Lampinen et al., 2023; Hansen et al., 2023). Although public support for biodiversity-focused UGI is high, challenges remain in incorporating ecological considerations into UGI design and governance (Grabowski et al., 2023). Diverse planting styles contribute to climate adaptation (Doussard et al., 2023), but the multifunctionality of UGI is still underutilized (Morpurgo et al., 2023). Effective strategies must involve adaptive management and public engagement (Wang et al., 2022). Another critical benefit of UGI is carbon sequestration. Urban trees, green roofs, and vegetated areas help offset emissions and store carbon. Case studies from Tehran and China show significant CO2 reduction through urban greenery (Rasoolzadeh et al., 2024; Tan et al., 2023). However, carbon storage capacity varies by species and soil condition (Shafique et al., 2020), reinforcing the importance of spatial planning and species selection (Nair et al., 2015; Bellet et al., 2003).

The interconnected benefits of UHI mitigation, biodiversity conservation, ecological connectivity, and carbon sequestration emphasize UGI's multifunctional value. Urban forests, for example, reduce temperatures and serve as carbon sinks and biodiversity hubs (Farid et al., 2024). Ecological corridors enhance habitat connectivity while providing cooling and storage services (Xiao et al., 2020; Dong et al., 2024). Despite this potential, many studies have addressed these functions separately. Few have integrated UGI performance across all four dimensions, namely UHI mitigation, biodiversity, ecological corridors, and carbon sequestration, particularly in fast-developing areas like Sancaktepe in Istanbul, where urban pressures exacerbate climate vulnerability (Pala et al., 2024; Hidalgo García, 2023). This study addresses this gap by evaluating the multifunctionality of Urban Green Infrastructure in the Sancaktepe District through a composite Urban Green Infrastructure Performance Index (UGI-PI), created by the authors using satellite-based spatial indicators. In addition to the UGI-PI, the research incorporates secondary data provided by YAYSIS, including biodiversity information, land use classifications, and an ecological corridor map. These datasets, originally developed and published by YAYSIS. Together, the integration of primary and secondary data enables the identification of both high performing green zones and vulnerable urban areas in need of strategic intervention. The findings contribute to informed decision-making and support more climate adaptive and ecologically resilient urban planning in Istanbul.

2. Materials and Methods

2.1 Study Area: Sancaktepe Municipality

Study was conducted in Sancaktepe, located on the Asian side of Istanbul, situated between longitudes 29.14°E and 29.26°E and latitudes 40.96°N and 41.02°N (Figure 2). Sancaktepe represents a rapidly urbanizing district with a mix of residential, commercial, and green spaces, covering an area of approximately 62 km² and housing over 230,000 residents. The district is bordered by forests to the north and south, with its northeastern section falling within the water basin of Lake Ömerli (Dubovyk et al., 2011). Its proximity to forested areas and ongoing urban development makes it an ideal location to assess the multifaceted impacts of UGI.

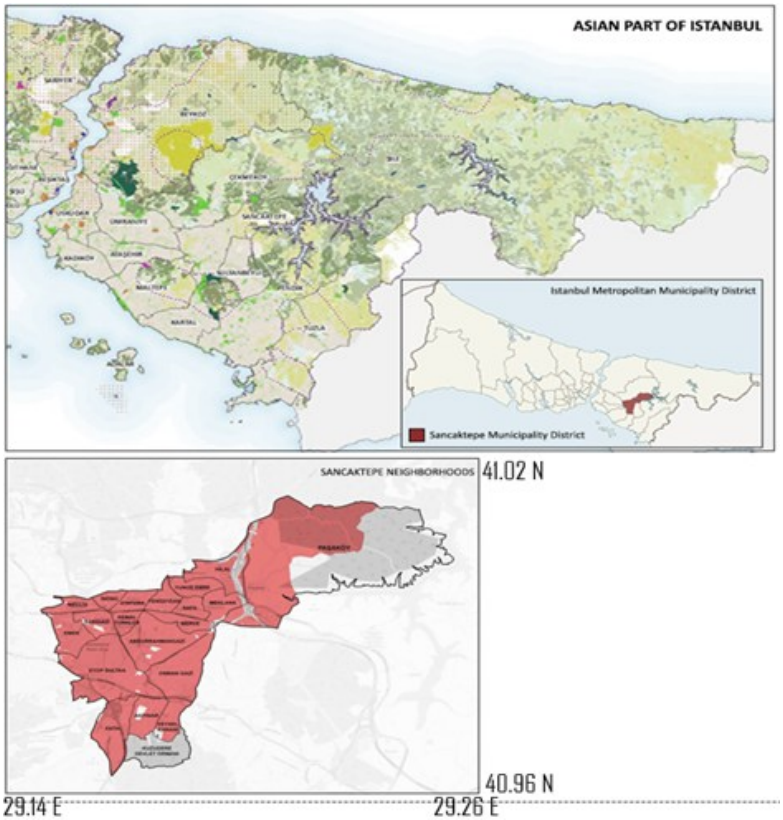

Fig. 2. Location of Sancaktepe in İstanbul

Sancaktepe was chosen for this study because it represents a rapidly urbanizing district shaped by the city's expansion into environmentally sensitive areas. Despite this growth, it maintains a moderate level of green infrastructure, including public parks, urban forests, and green corridors, which cover approximately 30 percent of its total area. Notably, Aydos Forest, one of Istanbul's most ecologically significant green spaces, enhances the district's biodiversity, with dominant species such as Turkish pine and oak. In addition to these natural zones, the Atatürk Street corridor in the urban core was selected as a representative site for evaluating afforestation efforts. Field data collected from this location were used to estimate carbon sequestration potential. Given its combination of urban pressure and ecological assets, Sancaktepe serves as a relevant case study for assessing the multifunctional role of Urban Green Infrastructure in climate adaptation, particularly in mitigating Urban Heat Island effects and supporting environmental resilience.

2.2 Methodological Approach and Data Source

This study adopts a mixed methods approach that combines spatial analysis, literature review, and empirical field measurements to assess the multifunctional performance of Urban Green Infrastructure (UGI). The research begins with a comprehensive literature review to establish the conceptual and theoretical framework of UGI. This includes an exploration of its core ecological functions, including carbon sequestration, biodiversity support, mitigation of the urban heat island effect, and ecological connectivity. These themes collectively inform the analytical scope of the study. Spatial indicators were extracted from Landsat 8 to derive three key biophysical indicators: Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Built-up Index (NDBI). These indicators were processed using QGIS Desktop 3.34.15, a widely used open-source geographic information system platform, to evaluate the spatial performance of Urban Green Infrastructure (UGI) across the Sancaktepe District. LST was derived from Band 10 of the Landsat 8 Thermal Infrared Sensor (TIRS). The raster data was imported directly and converted to degrees Celsius within the GIS environment to visualize surface temperature variations across the district. This allowed for the identification of heat patterns and evaluation of vegetation's cooling effects in urban areas. The formula used is:

$$\text{LST}\,(°\text{C}) = (\text{DN} \times \text{ScaleFactor} + \text{AddOffset}) - 273.15 \qquad (1)$$

Here, DN refers to the digital number from Band 10, while ScaleFactor and AddOffset are calibration constants provided in the metadata. The value 273.15 is subtracted to convert the result from Kelvin to Celsius.

NDVI was calculated using Band 4 (Red) and Band 5 (Near Infrared) of Landsat 8 (Codemo et al., 2022; Nikkala et al., 2022). The formula used is:

$$\text{NDVI} = \frac{NIR - Red}{NIR + Red} \qquad (2)$$

This index quantifies the presence and density of green vegetation, helping to assess the ecological health of green infrastructure.

NDBI was calculated using Band 5 (Near Infrared) and Band 6 (Shortwave Infrared 1) of Landsat 8 (Nikkala et al., 2022) using the formula:

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR} \qquad (3)$$

NDBI is used to detect impervious surfaces and built-up density, which influences urban heat retention and UGI effectiveness.

Each of the three indicators was normalized using the min-max normalization method to allow comparability and integration. Several previous studies have utilized these indicators individually or in combination to assess aspects of urban environmental quality and surface dynamics, such as vegetation analysis using NDVI (Sonali & Paul, 2021), built-up density estimation using NDBI (Yasin et al., 2022), and urban thermal patterns using LST (Rees et al., 2024). Several studies have combined spatial indices to better understand the dynamics of urban heat. For instance, Sharma and Vashishtha (2023) utilized NDBI, NDVI, and NDWI together to assess their correlations with land surface temperature (LST) across different seasons and time periods. Similarly, Abdulwahab and Drambi (2021) conducted a multi-epoch analysis using NDBI, NDVI, and LST to examine the spatiotemporal dynamics of land use/land cover and their relationship with urban heat patterns. This research proposes an original composite index called the Urban Green Infrastructure Performance Index (UGI-PI) to evaluate the multifunctional effectiveness of green infrastructure. The UGI-PI was calculated using the following formula:

$$UGI - PI = \frac{Normalized\ NDVI + (1 - Normalized\ NDBI) + (1 - Normalized\ LST)}{3} \qquad (4)$$

This formulation aligns all indicators so that higher values represent better green infrastructure performance, reflecting vegetation presence, built-up intensity, and land surface temperature. The resulting index was classified into five performance categories using equal interval classification to illustrate spatial disparities in green infrastructure effectiveness across the study area. Additionally cological corridor data, land use classifications, and biodiversity information obtained from the YAYSIS, the Green Area Management System of Istanbul. Datasets are shown in Table 1.

Tab. 1. Summary of Data Sources and Applications

Dataset	Data Source	Description	Application
Land Use Map	Sancaktepe Municipality	Spatial data demonstrating land use distribution in Sancaktepe	Used to evaluate green infrastructure and urban greenery
Land Surface T emperature (LST)	Created by authors using Landsat 8	Raster data showing spatial surface temperature variation across Sancaktepe	Analyze thermal patterns and assess urban heat island mitigation via green infrastructure
Vegetation Index (NDVI)	Created by authors using Landsat 8 imagery	Derived vegetation index values representing greenness and vegetation density	Evaluate vegetation cover and support UGI-PI calculation
Built-up Index (NDBI)	Created by authors using Landsat 8 imagery	Index representing built-up intensity and impervious surface distribution	Identify urbanized areas and assess land cover impact on UHI and UGI performance
Composite Index (UGI-PI)	Developed by authors	Composite spatial index integrating LST, NDVI, and NDBI	Assess and map the multifunctional performance of UGI across the district
Ecological Corridors	YAYSIS Report 106 (Ventilation and ecological corridors of Istanbul)	Data on existing and projected ecological corridors in Sancaktepe	Evaluate connectivity and biodiversity enhancement through UGI initiatives.
Carbon Sequestration Calculations	Created by authors (field measurements and dry weight table)	Carbon sequestration calculated by using average tree circumference and dry weight references (Table 2)	Quantify carbon storage of the afforestation project with 11,000,000 trees planted across settlement areas

The outputs helped identify areas with strong UGI performance and highlight zones that are vulnerable and in need of targeted greening interventions. The resulting spatial analysis supports evidence-based urban planning aimed at improving ecological resilience in Istanbul's rapidly developing districts. The flow of the applied methodology is presented in Figure 3.

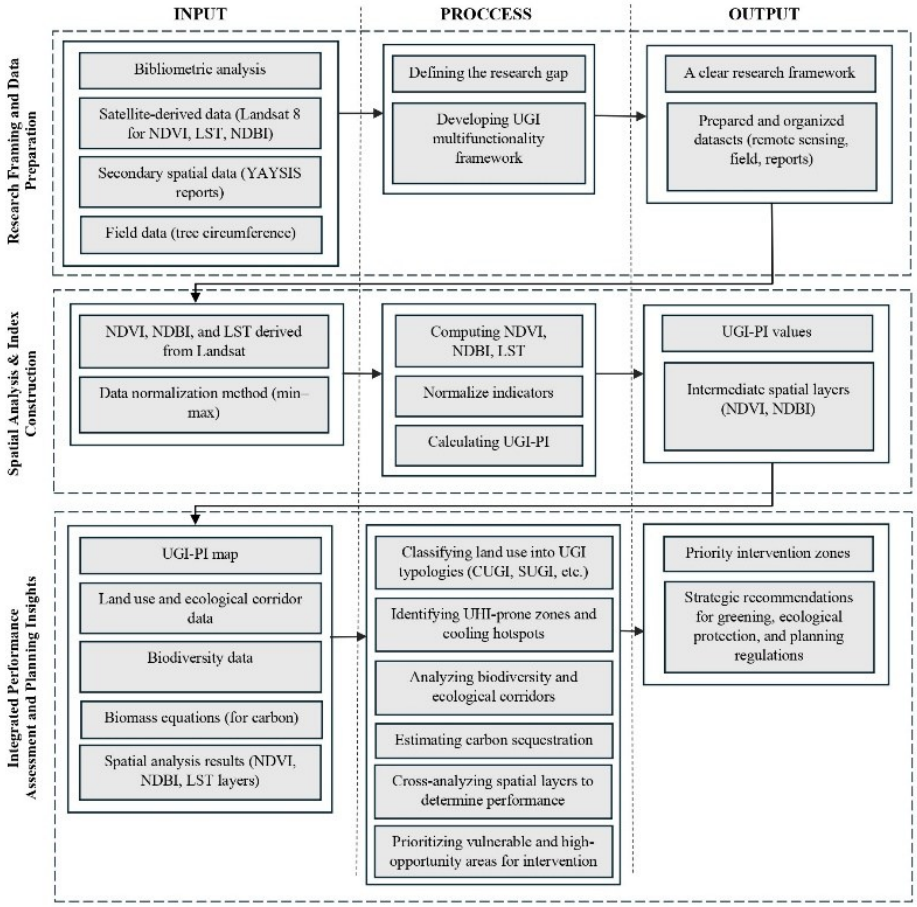

Fig. 3. Flowchart of the methodological framework used in the study

3. Results and Discussion

3.1. Land Use and Green Infrastructure Distribution

The land use classification in Sancaktepe reveals the spatial distribution of green infrastructure and its contributions to climate resilience. Based on data from the YAYSIS platform, the district's land use was categorized into several functional zones: Core Urban Green Infrastructure (CUGI), Supporting Urban Green Infrastructure (SUGI), Built Environment with Potential for Green Integration (BEPGI), Hard Infrastructure with Green Potential (HIGP), Industrial and Commercial Zones (ICZ), and Special Areas (SA).

Core Urban Green Infrastructure accounts for the largest share at 38.21% (2,360 hectares). Among these, forests dominate the landscape, covering 2,167 hectares (35.08%), highlighting their critical role in carbon sequestration, biodiversity conservation, and urban cooling. Additional contributions come from parks and green spaces (0.53%), passive green spaces (1.02%), recreation areas (0.89%), and water bodies such as lakes and ponds, though these occupy smaller proportions. Supporting Urban Green Infrastructure makes up 7.8% (481 hectares), with agricultural land as the most significant sub-category (6.69%). These zones act as ecological buffers and enhance the connectivity between primary green infrastructure patches. Built Environment with Potential for Green Integration comprises 28.62% of the district (1,767 hectares). It includes current housing areas (25.54%), educational and social facilities, and commercial-residential zones. Although heavily urbanized, these areas present meaningful opportunities for green interventions such as green roofs, vertical gardens, and permeable paving to improve local microclimates and environmental performance. Hard Infrastructure with Green Potential accounts for 2.99% (183 hectares), consisting of facilities like logistics areas, public parking, and technical infrastructure zones. These spaces, while traditionally utilitarian, can also be adapted to support climate adaptation measures through bioswales, solar canopies, and urban greening initiatives. Industrial and Commercial Zones cover 7.38%, including commercial, industrial, and mixed-use zones, while Special Areas, such as military and fuel station areas, occupy a negligible 0.1%.

This detailed categorization, summarized in Table 2, provides essential insights into both the ecological strengths and the spatial potential for Urban Green Infrastructure (UGI) enhancement across the district. The data clearly show that while significant natural assets already exist in Sancaktepe, especially in forested zones, large portions of urbanized land offer opportunities for integrated green infrastructure strategies aimed at improving urban resilience and sustainability. To visualize these patterns, Figure 4 presents the land use classification map of Sancaktepe, illustrating the spatial distribution of forests, green areas, built-up zones, and infrastructure.

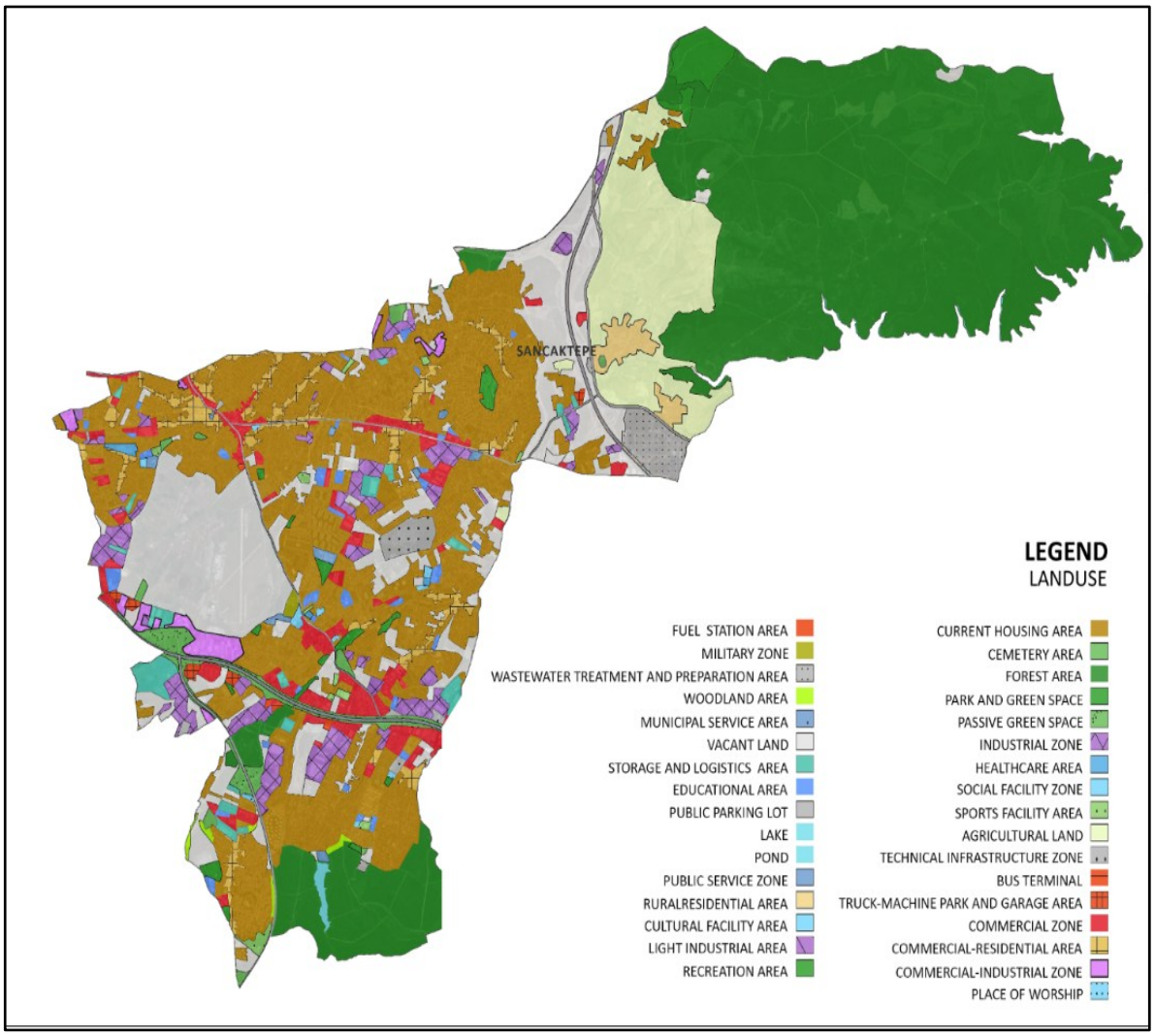

Fig. 4. Land use classification map of Sancaktepe District, illustrating the spatial distribution of urban functions (Istanbul Metropolitan Municipality, 2017).

Tab. 2. Land use classification and distribution in Sancaktepe District categorized by Urban Green Infrastructure (UGI) typologies.

Urban Green Infrastructure Categorization			
Category	**Area Type**	**Hectares (ha)**	**Percentage (%)**
Core Urban Green Infrastructure	*Woodland area*	9	0.15
	Forest area	2167	35.08
	Park and green space	33	0.53
	Passive green space	63	1.02
	Recreation area	55	0.89
	Lake	6	0.1
	Pond	9	0.14
	Cemetery area	18	0.3
	Total CUGI	**2360**	**38.21**
Supporting Urban Green Infrastructure	*Agricultural land*	413	6.69
	Rural residential area	46	0.74
	Sport facility area	18	0.3
	Cultural facility area	4	0.07
	Total SUGI	**481**	**7.8**
Built Environment with Potential for Green Integration	*Educational area*	44	0.71
	Place of worship	4	0.07
	Social facility zone	2	0.04
	Public service zone	9	0.14
	Current housing area	1577	25.54
	Commercial residential area	131	2.12
	Total BEPGI	**1767**	**28.62**
Hard Infrastructure with Green Potential	*Municipal service area*	7	0.12
	Wastewater treatment and preparation area	52	0.85
	Storage and logistics area	72	1.16
	Public parking lot	4	0.07
	Technical infrastructure zone	35	0.57
	Bus terminal	1	0.02
	Truck-machine park and garage area	12	0.2
	Total HIGP	**183**	**2.99**
Industrial and Commercial Zones	*Light industrial area*	3	0.04
	Industrial zone	199	3.23
	Commercial zone	206	3.33
	Commercial industrial zone	48	0.78
	Total ICZ	**456**	**7.38**
Special Areas	*Military zone*	4	0.07
	Fuel station area	2	0.03
	Total SA	**6**	**0.1**

3.2. UHI Mitigation-Oriented Spatial Analysis of LST, NDBI, and NDVI for UGI Performance Evaluation

The spatial analysis of Land Surface Temperature (LST), Normalized Difference Built-up Index (NDBI), and Normalized Difference Vegetation Index (NDVI) for the year 2023 provides a comprehensive understanding of how land cover patterns influence the urban thermal environment in Sancaktepe. The LST map indicates that densely built-up areas, especially central neighborhoods and main urban corridors such as Atatürk Street, experience significantly higher surface temperatures, frequently exceeding 46°C. In contrast, lower temperatures, ranging between 32°C and 35°C, are observed in regions adjacent to large green areas, particularly in the north and south. The NDBI map shows a concentration of positive index values (> 0.17 and between -0.05 to 0.17) in the central and western zones, confirming high levels of impervious surfaces and built-up density. These areas correspond with hotspots identified in the LST map, highlighting the role of urban morphology in exacerbating heat retention. Conversely, zones with negative NDBI values are mostly clustered around forested lands, aligning with cooler regions in the LST output.

Complementing this, the NDVI map reveals that vegetated areas, especially in the northern Ömerli Basin and southern forest edges, display high vegetation indices (NDVI > 0.4226), indicating dense, healthy vegetation. These green zones act as natural cooling agents, reducing ambient surface temperatures through evapotranspiration and shading. The spatial overlap between high NDVI values and lower LST readings clearly illustrates the cooling function of vegetation, while the inverse relationship between NDVI and NDBI reaffirms the negative correlation between green cover and built-up intensity.

Overall, these findings emphasize the critical importance of urban green infrastructure (UGI) in mitigating heat stress and improving microclimatic conditions. The integration of LST, NDBI, and NDVI metrics supports the argument that increasing vegetation cover and controlling urban sprawl are key strategies for enhancing thermal comfort and climate resilience in rapidly urbanizing districts such as Sancaktepe. To synthesize these three indicators into a unified spatial framework, a composite Urban Green Infrastructure Performance Index (UGI-PI) was developed. The index reveals clear spatial disparities in UGI effectiveness, with higher scores concentrated in the Ömerli Basin and Aydos Forest, indicating dense vegetation, low thermal stress, and limited built-up intensity. In contrast, lower scores are predominant in central and southern urban zones. This composite spatial tool offers an integrated assessment of UGI performance and supports the identification of priority areas for conservation and targeted greening interventions, as shown in Figure 5.

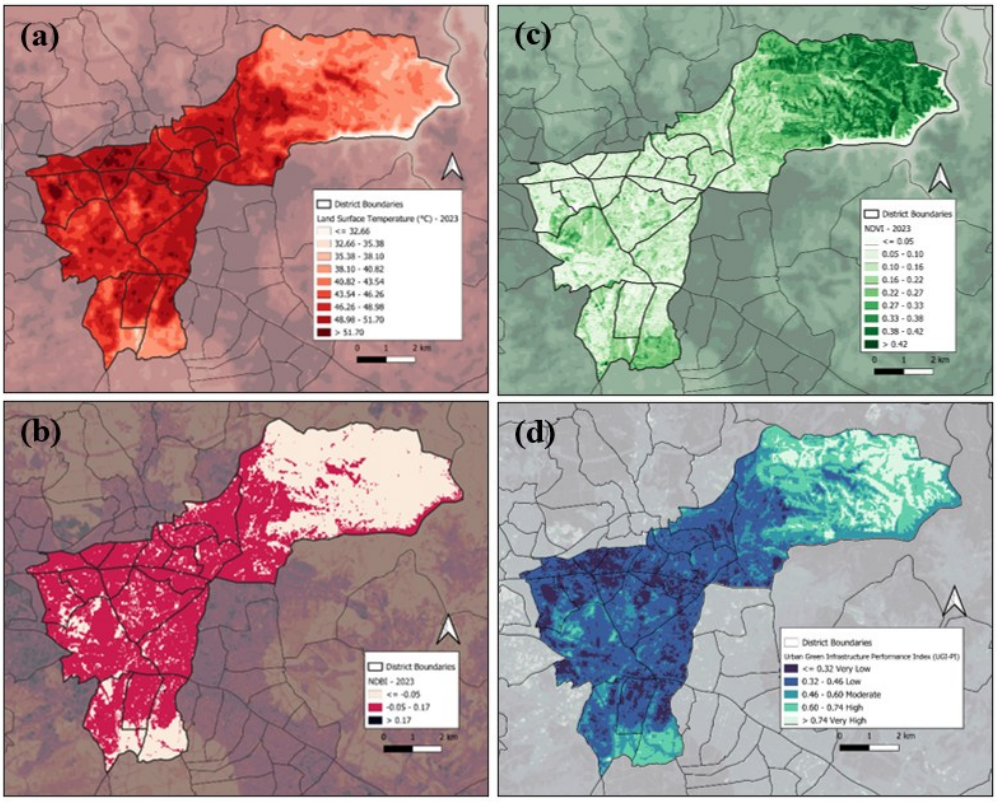

Fig. 5. Spatial distribution of (a) Land Surface Temperature (LST), (b) Normalized Difference Built-up Index (NDBI), and (c) Normalized Difference Vegetation Index (NDVI), and (d) composite Urban Green Infrastructure Performance Index (UGI-PI) for Sancaktepe.

3.3. Biodiversity Insights

Sancaktepe demonstrates high biodiversity relative to other districts in Istanbul, largely due to its rich natural assets. Conserved regions such as the Ömerli Basin, Aydos Natural Forest, and protected nature parks play a vital role in maintaining ecological integrity. In addition, monumental trees located in Bosna Park contribute to the district's natural heritage. According to biodiversity records, these areas host 224 plant taxa and 10 endemic species. Six different habitat types have been identified in the district, including oak coppice forests, scrublands, seasonal waterlogged ponds, reservoir shorelines, acidic peat bogs, and dry rocky plant communities (Özhatay et al., 2005). The total open green area in Sancaktepe covers approximately 321.68 hectares, encompassing pastures, recreational zones, urban forests, and natural woodland areas. Some rural-characterized sections of the district also contribute to its ecological diversity.

Among these, the Ömerli Basin emerges as a key biodiversity hotspot in Istanbul. Its natural forests span a study area of 15,052 hectares and support an exceptional diversity of flora and fauna. In addition to the previously noted 224 plant taxa and 10 endemic species, the basin is home to 58 species of lichen. Notably, three lichen species including Gyalolechia flavovirescens, Lobothallia cheresina, and Protoparmeliopsis laatokkensis were newly documented in this area, reflecting its high ecological value. These lichen-rich forests contribute to microclimate regulation and air quality improvement, while the diverse fauna supports the continuity of ecological corridors. Our study supports these findings by highlighting that natural vegetated zones like Ömerli and Aydos consistently demonstrate higher UGI Performance Index (UGI-PI) scores. Despite these strengths, the biodiversity in the Ömerli Basin is under increasing pressure from habitat fragmentation and water pollution caused by rapid urbanization and industrial activities. Pollution from settlements and land use changes have altered species compositions, as observed in the area around Osmangazi and Bilal streets. This highlights the urgent need for proactive planning policies that prioritize habitat connectivity, enforce conservation measures, and integrate biodiversity into urban development practices. The findings of this study emphasize that biodiversity should not be viewed as an isolated ecological concern but rather as an integral component of multifunctional UGI systems.

3.4. Ecological Corridors

The analysis of ecological corridors in Sancaktepe identified several green patches with high potential for ecological connectivity, playing a critical role in enhancing urban biodiversity and overall environmental resilience. Based on spatial data from the YAYSIS platform, green areas with substantial vegetation coverage were examined through GIS-based overlay analysis to establish ecological linkages across the district (Figure 6).

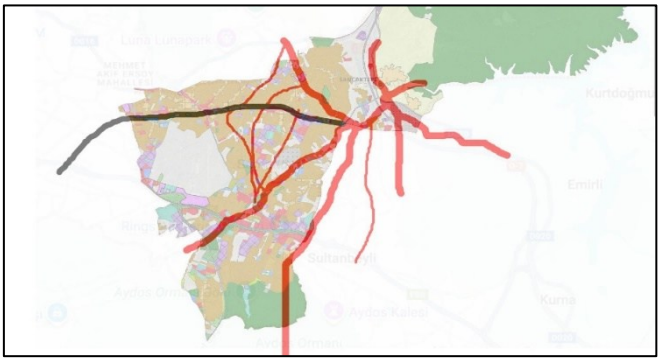

Fig. 6. Ecological corridors of Sancaktepe (YAYSIS).

These corridors serve key ecological functions by facilitating species movement, supporting habitat continuity, and contributing to urban climate adaptation. In particular, critical green patches were observed near the Ömerli Basin and Aydos Forest. These areas act as ecological nodes that support diverse habitats and are essential for maintaining biodiversity in Sancaktepe. Their strategic position within the district reinforces their importance in forming the backbone of an integrated urban ecological network.

Connectivity mapping suggested potential corridors between these significant green zones. These pathways offer opportunities not only for ecological conservation but also for microclimate regulation. Their alignment with the district's natural ventilation axes enhances airflow, reduces localized heat accumulation, and alleviates urban heat island effects in heavily built-up areas. This aligns with broader findings of the study, which underscore the strong correlation between vegetation presence and lower LST's. Establishing and maintaining ecological corridors not only safeguards biodiversity but also contributes to urban cooling, carbon sequestration, and improved environmental quality. In the context of Sancaktepe's ongoing development, ecological corridors present a practical and scalable strategy to achieve both conservation and climate resilience objectives.

3.5. Carbon Sequestration Results

Carbon sequestration plays a crucial role in mitigating climate change by capturing and storing carbon dioxide (CO_2) from the atmosphere. The afforestation project involving 11,000,000 trees across the Sancaktepe Municipality serves as a significant example of how urban green infrastructure can support climate adaptation. To estimate the approximate amount of carbon sequestration, field measurements were taken from plantation trees at a height of 1.30 meters. The average circumference was measured at 55-60 cm, and dry weight was calculated using a standard reference table (Table 3). Since the table is the reference for dry weight, the closest amount is taken for the circumference calculation in the field. 106 kg dry weight is taken in the table as the closest reference in our circumference measurement. The total carbon sequestration was then estimated using the formula (Forestry England, 2025)

$$Total\ Carbon\ Sequestration\ (tons) = \frac{3.67 \times (Dry\ weight)}{2} \qquad (5)$$

Resulting in an approximate value of 2,139,610 tons of carbon storage across settlement areas.

Tab. 3. Circumference (cm) Dry weight (kg)

Circumference (cm)	Dry weight (kg)
50	106
100	668
150	1964
200	4221
225	5771
250	7641
275	9842
300	12410
325	15350
350	18700
400	26674

4. Conclusion

This study examined the multifunctional nature of urban green infrastructure (UGI) in the Sancaktepe district, highlighting the diverse roles that green spaces play in the urban environment. Spatial analysis of land use patterns revealed the distribution of green and built-up areas, while indicators such as the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), and land surface temperature (LST) demonstrated that areas with more vegetation tended to have lower surface temperatures. Conversely, densely built-up zones were associated with higher heat signatures. A synthesized UGI Performance Index (UGI-PI) integrated these spatial factors to identify zones where green infrastructure provides the most extensive ecological benefits. Together, these analyses underscore how urban green spaces in Sancaktepe mitigate urban heat, improve environmental quality, and support multiple ecosystem functions simultaneously.

The integrated analysis of Sancaktepe's urban green infrastructure reveals a clear multi benefit pattern. Densely vegetated northern zones such as forested uplands and riparian corridors score highest on all indicators, while compact southern and central urban neighborhoods score lowest. High vegetation areas exhibit substantially lower LST and higher NDVI than built-up blocks, confirming that green cover provides strong urban cooling. Another issue is that surface temperatures have been observed to decrease in densely urbanized areas that contain natural green remnants and retain a rural character. Therefore, it is important to protect these green spaces within residential areas or leaving gaps in desnsely urbanized residentials. Crucially, the composite UGI-PI highlights

that areas maximizing climate regulation, carbon storage, and habitat quality coincide. These areas display high NDVI, low LST, extensive tree cover, and contiguous green patches, aligning with ecosystem services planning goals. The UGI-PI effectively identifies where multiple green benefits overlap, mapping out the high value green infrastructure network in Sancaktepe.

Biodiversity assessments in the study area further highlighted the ecological value of connected green spaces. The configuration of ecological corridors linking parks and woodlands emerged as crucial for maintaining species' richness and enabling wildlife movement across the urban landscape. These corridors foster a connected ecosystem that sustains habitat continuity and enhances habitat quality. The analysis also estimated the carbon sequestration potential of afforestation areas in residentials of Sancaktepe using biomass equations. Although plantations contribute meaningfully, mature natural vegetated areas such as the Ömerli Basin and Aydos Forest provide superior sequestration capacity due to their biodiversity and stable ecological structure.

Municipality could formally designate these northern zones as ecological corridors and parks, preventing development and improving connectivity through green streets and ecological buffers. Meanwhile, greening interventions should target heat prone neighborhoods in central and southern zones by planting trees, restoring degraded streamsides, or creating pocket parks. The practical implications of these findings are significant for climate resilient urban planning. The multifunctional benefits identified suggest that preserving and expanding green infrastructure should be a priority for sustainable urban growth. In Sancaktepe and similar rapidly urbanizing districts, planners and policymakers can use these insights to prioritize projects that maintain or create green corridors, protect mature trees, rural characterized abondoned gaps, and increase vegetated areas in new developments. Incorporating UGI considerations into zoning and development regulations can help reduce urban heat island effects while supporting ecological resilience. Such strategies will become increasingly important as cities face intensifying climate challenges and seek to safeguard environmental and human well-being.

However, the study's conclusions are subject to certain methodological limitations. The moderate spatial resolution of the remote sensing data limits the ability to detect small or fragmented green spaces, potentially underestimating the total vegetated area and its ecological impact. Landsat thermal imagery, even after resampling, represents 30-meter pixels, which may smooth over fine scale variations such as tree shaded areas or narrow urban parks. Small green features underrepresented in the NDVI or LST layers may be ecologically important but are not fully captured. The carbon storage estimates were derived from generalized biomass equations that may not reflect local species characteristics, age distribution, or specific soil conditions, introducing uncertainty into sequestration values. Additionally, findings are specific to Sancaktepe's urban context. While qualitative patterns such as the cooling and biodiversity benefits of green zones are broadly applicable, the specific index thresholds and spatial corridor networks may differ across other urban environments.

In conclusion, this research demonstrates that UGI is not only a climate mitigation tool but also a strategic urban resilience mechanism. By aligning conservation goals with planning interventions and community needs, districts like Sancaktepe can build more sustainable, healthy, and livable urban environments. The UGI-PI developed in this study offers a replicable model for identifying priority areas for conservation and targeted greening, supporting evidence based and equity focused urban climate adaptation strategies.

Acknowledgments

The authors also acknowledge the YAYSIS website and Its Strategy Document for providing important data and resources for the analysis performed in the present study. Finally, the authors would like to thank everyone who has contributed to this work in some way, whether through technical aid, encouragement, or shared discussions that have enhanced their understanding of the issue.

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