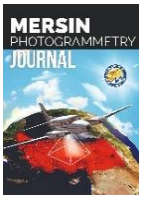
Mersin Photogrammetry Journal

https://dergipark.org.tr/en/pub/mephoj

e-ISSN 2687-654X



Evaluating urban green spaces using UAV-based green leaf index

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Cite this study: Akca, S. (2024). Evaluating urban green spaces using UAV-based green leaf index. Mersin Photogrammetry Journal, 6(2), 52-59.

https://doi.org/10.53093/mephoj.1536466

Keywords
UAV
Photogrammetry
Green Space Ratio
GLI

Research/Review Article

Received: 20.08.2024
Revised 1: 09.09.2024
Revised 2: 23.09.2024
Accepted: 25.09.2024
Published: 31.12.2024

Abstract

This study evaluates the urban green spaces at Harran University's Osmanbey Campus using UAV technology and the Green Leaf Index (GLI). By employing Structure-from-Motion (SfM) photogrammetry, a highly detailed orthophoto of the campus was generated, while the GLI helped to identify and measure the green areas accurately. The analysis revealed that the Total Green Space Area on the campus is 8.8 hectares, within a Total Urban Area of 46.4 hectares. This results in a Green Space Ratio (GSR) of 18.97%. This percentage indicates that nearly 19% of the campus' urban area is covered by green spaces, which represents a moderate yet meaningful level of vegetation that enhances the environmental quality and overall well-being of the campus community. The findings underscore the value of incorporating UAV-based metrics into urban green space assessments and suggest that increasing the GSR to around or above 20% could provide even greater ecological and social benefits.

1. Introduction

Urban green spaces are vital components of city landscapes, offering a range of ecological, social, and health benefits that significantly enhance the quality of life for urban residents. These spaces include parks, gardens, green roofs, and other vegetated areas that not only contribute to urban biodiversity but also help mitigate the urban heat island effect. Additionally, they provide essential recreational opportunities and contribute to the overall mental and physical well-being of city dwellers. Therefore, the effective assessment and management of urban green spaces are crucial for promoting sustainable urban development and ensuring the long-term health of urban environments [1].

Unmanned Aerial Vehicles (UAVs) are increasingly utilized in various fields today, particularly in military applications, as well as in geological and meteorological research, disaster management, international border patrols, forest fire detection, deformation analysis, mapping of the Earth's surface, and 3D modeling of cities or terrains. The use of these aerial vehicles offers numerous advantages in the field of cartography. UAVs equipped with digital cameras can capture images that enable measurements in areas that may be difficult or dangerous for humans to access. The measurements obtained using images from UAVs can be nearly as precise as those obtained through ground-based techniques, making them a viable alternative to traditional survey methods [2].

Moreover, UAVs offer several advantages over satellite imagery. UAVs can produce images with spatial resolutions that are currently unattainable with satellite images. Additionally, UAVs can capture images at the desired time, overcoming some of the challenges associated with satellite imagery, such as long waiting times and unsuitable weather conditions that may prevent the acquisition of high-quality images. UAVs can also provide high temporal resolution images. Another advantage of UAVs is their ability to obtain images at a lower cost compared to satellite imagery. The capability of UAVs to capture high-resolution images at a lower cost and with greater flexibility compared to traditional satellite methods positions them as a significant technological advancement in modern surveying and mapping practices [2].

In recent years, advancements in remote sensing technologies, particularly the deployment of UAVs, have revolutionized the monitoring and analysis of urban green spaces. UAVs, equipped with high-resolution cameras and sensors, can capture detailed imagery and data, which enable a more precise and comprehensive assessment of vegetation health and distribution within urban areas. Among the various indices used in these assessments, the Green Leaf Index (GLI) stands out for its ability to measure vegetation greenness based on the visible spectrum [3]. The GLI is especially advantageous in urban green space assessments due to its simplicity and the widespread availability of red, green, and blue bands (RGB) imagery, making it both cost-effective and accessible.

Unlike other vegetation indices that require specialized sensors, the GLI can be derived from standard RGB cameras, which are commonly available. This accessibility does not diminish the index's effectiveness; in fact, it enhances its practicality for urban planners and environmental managers who require reliable and easy-to-use tools for assessing green spaces [4]. The simplicity and efficacy of the GLI make it a valuable assessment in urban green space management, particularly in efforts to promote sustainability and improve environmental quality.

Several recent studies have demonstrated the effectiveness of UAV-based indices like the GLI in urban green space assessments. For example, a study by Liu et al. (2020) utilized UAV imagery to evaluate the spatial distribution of green spaces in Shanghai, highlighting the advantages of high-resolution UAV data in capturing detailed vegetation patterns [5]. This study suggests that integrating UAV technology could significantly enhance urban planning and management efforts by providing more accurate and timely data. Similarly, research conducted by Xie and Weng (2017) in Indianapolis used UAVs to monitor urban vegetation, showcasing the potential of UAVs to deliver valuable insights into the health and distribution of urban green spaces [6].

Lahoti et al. (2020) developed a UAV-based approach to urban green space production aimed at mitigating the lack of geospatial data and enhancing urban planning in Indian cities [7]. Liang et al. (2017) conducted a three-dimensional green space assessment using urban green space data for China, allowing for the examination of the environmental and climatic contributions of green spaces [8]. Yang (2018) identified green areas in the Gobi Desert at low altitudes by utilizing various vegetation indices, including the GLI [9]. Wang et al. (2020) measured the potential for herbal medicine planting in China by employing a UAV-based GLI, observing variations in GLI across different spatial locations [10].

Cao et al. (2021) identified green area phenotypes for wheat populations using UAV-based and multispectral images [11]. Blancon et al. (2019) also applied the GLI index to UAV-based images to assess wheat phenotypes [12]. Bassinee et al. (2019) employed image color indices and the GLI to identify plant regions using UAV images [13]. Kalisperakis et al. (2015) estimated crop leaf areas from hyperspectral UAV images, while Wang et al. (2023) monitored cultivated pasture areas using the Leaf Area Index, alongside observing textural characteristics [14-15].

These studies collectively demonstrate the diverse applications of UAV-based imagery and vegetation indices like the GLI in environmental monitoring, agriculture, and urban planning. By utilizing these advanced remote sensing techniques, researchers have been able to gather critical data on vegetation health, urban green spaces, and agricultural potential, thereby contributing valuable insights into environmental management and sustainable development.

This study specifically focuses on assessing the urban green spaces of Harran University Osmanbey Campus using UAV-based remote sensing techniques. The study aims to evaluate the greenness and health of the campus's vegetation by capturing high-resolution RGB imagery with UAVs and applying the GLI. The primary objectives include mapping the spatial distribution of green spaces across the campus and analyzing the health of vegetation in different areas. Effectively managing and enhancing these green spaces is essential not only for the well-being of the campus community but also for supporting the university's broader sustainability goals [16].

Reflections from the sun and sky on water surfaces, such as rivers and lakes, can cause distortions when captured by UAV sensors, which in turn can lead to insufficient point cloud density and accuracy. Additionally, in polluted water bodies, like those found in the study area, where the reflections tend to be greenish, accurately detecting vegetation becomes challenging. Unlike previous studies in the literature, this research overcomes these limitations with the proposed methodology.

The methodology for this study involves conducting UAV flights over the campus to collect RGB imagery, followed by processing these images to calculate the GLI. Spatial analysis will then be performed to assess the distribution and health of the campus's vegetation. Through this approach, the study aims to provide valuable insights that can inform the strategic management and improvement of urban green spaces at Harran University, ultimately contributing to the university's environmental and sustainability initiatives.

2. Study Area

Harran University is a prominent institution located in Şanlıurfa, Turkey, with its main campus situated at Osmanbey, approximately 20 kilometers from the city center. The Osmanbey Campus serves as the central hub for the university's academic, administrative, and research activities [17].

The Osmanbey Campus is noted for its commitment to sustainability and environmental stewardship. The campus has been designed to include extensive green spaces, contributing to the overall environmental quality and providing areas for relaxation and recreation. The university actively participates in tree planting and conservation programs, reinforcing its role as an environmentally conscious institution (Figure 1).

Harran University engages in several sustainability projects, including efforts to reduce the campus' carbon footprint, promote renewable energy use, and enhance water conservation. These initiatives are integrated into the campus operations and are also a focus of academic research and student involvement.

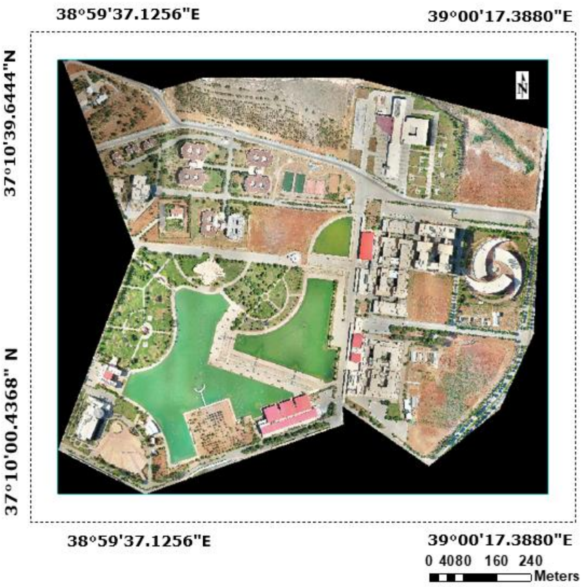

Figure 1. Osmanbey campus

3. Material and Methods

A series of photographs were taken using a UAV to create an orthophoto of the Osmanbey Campus. The captured images were of high resolution, with sufficient overlap to ensure high accuracy. The photographs were taken with the DJI Mavic 2 Pro, as shown in Figure 2. Following the photogrammetric flights, 918 photographs were obtained. Agisoft Photoscan software was used to process the photographs and create the orthophoto. The workflow applied in the Agisoft software.

Figure 2. DJI Mavic 2 Pro UAV system used in the study

3.1. Structure from motion (S*f*M) photogrammetry

To generate a comprehensive and detailed orthophoto of Harran University Osmanbey Campus, we employed the advanced technique of Structure from Motion (SfM) photogrammetry. This method, which has become increasingly popular for its precision and efficiency, involves the collection of a series of overlapping aerial photographs. These photographs were captured using a UAV equipped with a Hasselblad RGB camera, which can capture high-resolution images from various angles [18].

The process begins with the UAV systematically flying over the campus, capturing many images that overlap each other. In this study, the transverse overlap was 70%, and the longitudinal overlap was 80%. This overlap is crucial as it allows the photogrammetry software to identify common features across multiple images [19]. By analyzing these shared features, the software can reconstruct the relative positions and orientations of the camera during each photograph. This reconstruction is achieved through complex algorithms that calculate the spatial relationship between the features in the images, ultimately producing a 3D point cloud.

The 3D point cloud serves as the foundational data structure for the subsequent creation of a detailed 3D model. Each point in the cloud corresponds to a specific location in the real world, representing the surface of the terrain, buildings, and vegetation on the campus. The density and accuracy of this point cloud are determined by the quality and resolution of the captured images, as well as the precision of the camera's positioning data.

Once the point cloud is generated, it is further processed to create a fully textured 3D model. This model provides a highly accurate representation of the campus's topography and structures, including the detailed vegetation cover. The 3D model can be used for a wide range of applications, from environmental analysis to urban planning and architectural design [20].

S*f*M photogrammetry has gained widespread use across various fields, including archaeology, geology, and environmental science, due to its ability to produce high-resolution 3D models from 2D images with remarkable accuracy [21,22]. It is particularly valued for its cost-effectiveness compared to traditional surveying methods, as well as its ability to cover large areas quickly. The ability to generate precise 3D models without the need for specialized equipment beyond a UAV and standard camera makes S*f*M photogrammetry an accessible tool for many types of research and professional projects [23,24].

3.2. Orthophoto production

Objects in an original remotely sensed image are not located in their true positions due to displacements caused by sensor tilt and elevation differences [25]. The process of orthorectification corrects these errors resulting from such displacements. In the orthorectification process, a digital elevation model (DEM) of the area is used to correct errors caused by elevation differences. The required elevation data is obtained through interpolation from the DEM. The accuracy of the DEM and the spatial resolution of the images used directly affect the accuracy and resolution of the orthophoto maps. A coarse DEM may represent regions with small elevation differences, whereas in regions with significant slopes, the DEM must closely fit the area. The input data used for orthophoto production include aerial photographs or satellite images of the area, camera calibration information, interior orientation parameters, exterior orientation parameters for each photograph, and the DEM of the area to determine the elevations of the objects to be rectified [26].

The exterior orientation parameters of the images used in orthophoto production are determined using projection equations and control points identified on the ground. The control points chosen in the field should be prominent detail points with known coordinates and should be evenly distributed across the study area. The accuracy of the control points directly affects the accuracy of the digital orthophoto [27].

In addition to control points, tie points with unknown coordinates are automatically assigned by the software. The coordinates of these tie points are automatically calculated during the triangulation phase. The relationship between the terrain (reference) coordinate system and the photo coordinate system is established using projection equations. In orthophoto production, an empty grid structure is defined, segmented pixel by pixel. The coordinates of the center of each pixel in the grid within the terrain coordinate system are known.

The elevation values for these center points are obtained from the DEM, and the transition to the photo coordinate system is made using projection equations. From the calculated photo coordinates, pixel coordinates are determined. Since pixel coordinates generally do not correspond to the pixels in the image, one of the resampling methods is applied for each pixel segmentation, and the orthophoto map is obtained [2,26]. The orthophoto production workflow is given in Figure 3.

3.3. Green leaf index (GLI)

The GLI is a valuable vegetation index that provides an estimation of the greenness and overall health of plant life, making it a crucial tool in environmental monitoring and management. The GLI is calculated using the visible spectrum bands—specifically red, green, and blue (RGB)—from standard digital imagery. This index is particularly advantageous because it utilizes readily available RGB imagery, which is common in most cameras, including those mounted on UAVs [3].

One of the key benefits of the GLI is its accessibility and cost-effectiveness. Unlike other vegetation indices that require specialized sensors to capture near-infrared (NIR) data, the GLI can be derived from any standard RGB camera. This makes it a practical tool for a wide range of applications, from large-scale environmental assessments to smaller, localized studies. The fact that the GLI can be easily obtained from UAV-mounted cameras further enhances its utility, allowing researchers and environmental managers to conduct detailed vegetation assessments without the need for expensive or complex equipment.

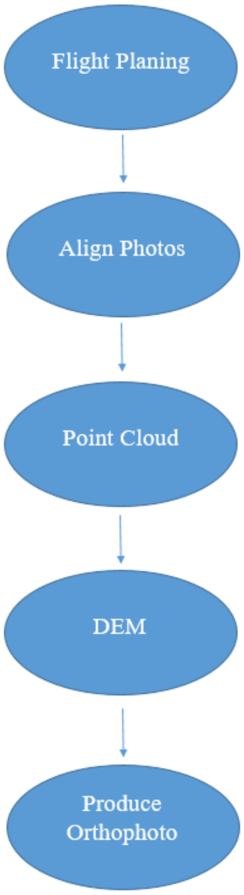

Figure 3. Workflow of the Agisoft Metashape

The GLI is particularly sensitive to chlorophyll content within vegetation, which is a direct indicator of plant health and vigor. Chlorophyll is the green pigment responsible for photosynthesis, and its presence is essential for the growth and sustainability of plants. By analyzing GLI values, researchers can gain insights into the health of vegetation—higher GLI values typically reflect healthier plants with abundant chlorophyll content, while lower values may signal stress, disease, or poor overall health [3].

The application of the GLI in vegetation assessments is broad and varied. In agricultural settings, for instance, it can be used to monitor crop health, detect areas of stress, and guide decisions on irrigation and fertilization. In urban environments, the GLI can be used to assess the condition of green spaces, such as parks and gardens, helping urban planners and environmental managers maintain and improve these areas for public use.

Moreover, the simplicity of the GLI calculation, combined with its reliance on commonly available technology, makes it an ideal choice for projects where budget constraints or limited access to advanced equipment might otherwise pose challenges. Its use in UAV-based monitoring allows for efficient, large-scale assessments, providing detailed and up-to-date information on vegetation health across extensive areas.

In summary, the GLI is a powerful yet accessible tool for assessing the greenness and health of vegetation. Its reliance on standard RGB imagery makes it a cost-effective and practical option for a wide range of applications, from agriculture to urban planning. The GLI's sensitivity to chlorophyll content enables accurate monitoring of plant health, providing valuable data that can inform environmental management practices and support sustainable development efforts.

The formula for GLI is given in Equation 1 where (R), (G), and (B) represent the red, green, and blue bands of the image, respectively. This formula was implemented using the Band Math tool in ENVI software.

$$GLI = \frac{2\times G - R - B}{2\times G + R + B} \qquad (1)$$

3.4. Green space ratio (GSR)

The Green Space Ratio (GSR) is a crucial metric in urban planning, serving as a quantitative indicator of the proportion of green spaces within a given urban area. This ratio is calculated by dividing the total green space area by the total urban area, offering a straightforward yet powerful measure of urban greenness [8]. The GSR is integral to sustainable urban development, as it directly influences environmental quality, biodiversity, and the overall well-being of urban residents.

A higher GSR signifies a greater presence of green spaces within the city, which is associated with a multitude of environmental, social, and health benefits. Green spaces, such as parks, gardens, and green rooftops, play a vital role in improving air quality by filtering pollutants and producing oxygen. They also contribute to temperature regulation, mitigating the urban heat island effect—a phenomenon where urban areas experience higher temperatures than their rural surroundings due to extensive concrete and asphalt surfaces that absorb and retain heat.

In addition to their environmental benefits, green spaces are essential for stormwater management. Vegetated areas help absorb rainwater, reducing the burden on urban drainage systems and minimizing the risk of flooding. Moreover, these spaces provide critical habitats for urban wildlife, supporting biodiversity even in densely populated areas.

Beyond their ecological impact, green spaces offer substantial social and health benefits. Numerous studies have demonstrated that access to green spaces can reduce stress levels, promote mental well-being, and encourage physical activity [10-13]. Urban residents with access to parks and recreational areas are more likely to engage in regular exercise, leading to improved physical health. Furthermore, green spaces foster social cohesion by providing communal areas where people can gather, interact, and strengthen community bonds.

In urban planning, the GSR is often employed as a benchmark for setting targets related to green space provision. It helps urban planners and policymakers assess the adequacy of green spaces within a city and monitor the progress of urban greening initiatives. By aiming to achieve higher GSR values, cities can enhance their environmental resilience, improve the quality of life for residents, and move closer to sustainability goals.

The formula for GSR is given in Equation 2.

$$\left(\frac{Total\ Green\ Space\ Area}{Total\ Urban\ Area}\right) \times 100 \qquad (2)$$

The GSR is derived from two key components: the "Total Green Space Area" and the "Total Urban Area." The Total Green Space Area encompasses all vegetated areas within the urban boundary, including parks, gardens, green rooftops, and other designated green spaces. In contrast, the Total Urban Area includes all land uses within the urban boundary, such as buildings, roads, pavements, parking sites, sports facilities, and both developed and undeveloped lands. This comprehensive approach ensures that the GSR provides an accurate reflection of the balance between green spaces and built environments in urban areas.

Ultimately, the GSR is not just a measure of greenery in cities; it reflects a city's commitment to sustainability, environmental stewardship, and the well-being of its inhabitants. As urban populations continue to grow, the GSR will play an increasingly important role in guiding the development of cities that are not only functional and efficient but also healthy, vibrant, and sustainable places to live.

4. Result

For the purposes of this study, only the areas of the campus containing faculties, dormitories, and housing—spanning over 600 hectares—were included. The portions of the campus with no human activity were excluded. As a result, an orthophoto covering approximately 47 hectares was analyzed. Within the study area, three artificial water pools were masked out because they interfere with the vegetation index (Figure 4).

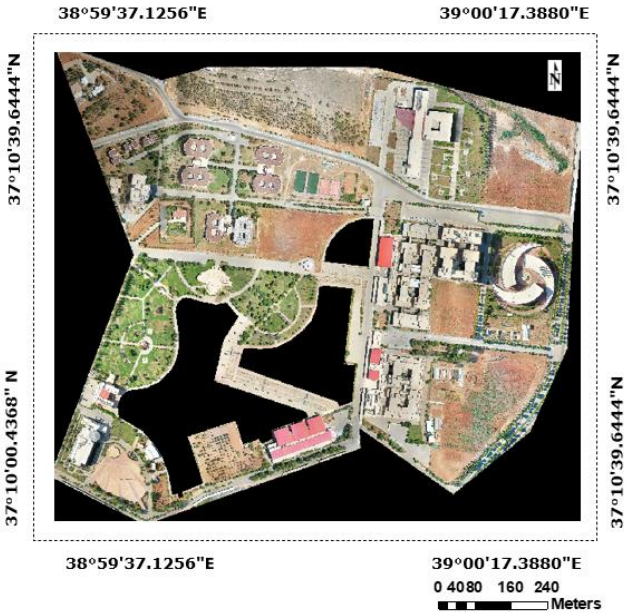

Figure 4. Orthophoto with masked water areas: Osmanbey campus

The GLI index was calculated according to Equation 1 by using the masked orthophoto given in Figure 1. The index values range between -1 and 1. All healthy and unhealthy vegetation have a GLI value greater than zero. A threshold value was used to delineate these vegetation areas (Figure 5).

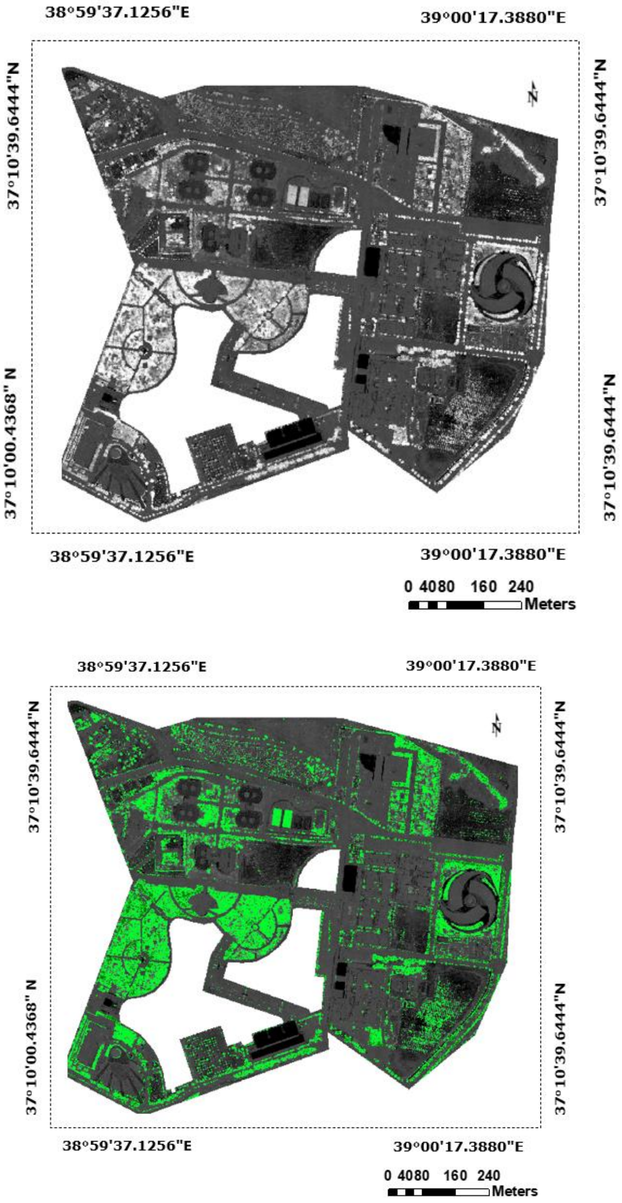

Figure 5. GLI results and its colored image

When the GLI index is examined alongside the orthophoto in Figure 1, it becomes clear that the index is highly effective at detecting green areas. For the remainder of the study, the calculation of the GSR requires determining the "Total Green Space Area" and the "Total Urban Area." In this context, the "Total Urban Area" represents the entire study area, encompassing 46.4 hectares. The "Total Green Space Area," calculated using the GLI index, which highlights vegetation, was determined to be 8.8 hectares, as illustrated in Figure 5.

5. Discussion

The European Environment Agency (EEA) recommends that cities should allocate at least 20-25% of their total area to green spaces to enhance environmental sustainability and improve the quality of life for residents [28]. In this context, the GSR for the Harran University Osmanbey Campus was calculated using a specific formula, resulting in a value of 18.97%. This figure reveals that approximately 19% of the campus's urban area is dedicated to green spaces, which is a significant proportion, especially within an academic environment.

A GSR of 18.97% indicates a substantial presence of green areas on the campus, which play a crucial role in maintaining environmental quality and supporting the well-being of students, faculty, and staff. Green spaces on a campus contribute to a healthier environment by mitigating the urban heat island effect, enhancing air quality, and providing essential recreational areas where the campus community can relax, exercise, and socialize.

Although the current GSR of 18.97% reflects a healthy and moderate level of green coverage, aligning with broader urban sustainability goals, there is still room for improvement. Increasing the GSR to closer to or above the 20% threshold recommended by the EEA could offer even greater ecological and social benefits. For instance, additional green spaces could further reduce heat retention in built-up areas, support greater biodiversity, and provide more opportunities for outdoor activities, thereby fostering a more vibrant and sustainable campus environment. The GSR value of 18.97% at Harran University Osmanbey Campus is a positive indicator of the institution's commitment to environmental stewardship.

Furthermore, the methodologies employed in this study are scalable and adaptable, making them suitable for application in other urban environments. As cities continue to expand and face the challenges of climate change, the importance of monitoring and enhancing green spaces cannot be overstated. Implementing UAV-based remote sensing techniques, such as those used in this study, can play a critical role in promoting urban sustainability and ecological health.

In addition to offering a blueprint for similar studies, this research also supports the broader adoption of advanced remote sensing technologies in urban planning and environmental management. By providing detailed insights into the distribution and health of green spaces, these tools can inform policy decisions, guide the development of urban green infrastructure, and ultimately contribute to the creation of more resilient and sustainable cities.

6. Conclusion

In this study, the combined use of the GLI and S*f*M photogrammetry proved to be highly effective in identifying and quantifying green spaces across the Harran University Osmanbey Campus. By leveraging UAV-based remote sensing technology, the study was able to produce a detailed analysis of the campus's vegetative cover, culminating in the calculation of a GSR of 18.97%. This GSR value signifies that nearly 19% of the campus area is devoted to green spaces, underscoring the university's commitment to maintaining a healthy and sustainable environment for its students and staff.

The significance of this finding lies not only in the quantitative measure of green space but also in its implications for the overall environmental quality and the well-being of the campus community. Green spaces are integral to reducing the urban heat island effect, improving air quality, and providing areas for recreation and relaxation. For a university setting, these spaces also enhance the aesthetic appeal of the campus and create a conducive environment for learning and social interaction, contributing to the mental and physical well-being of its occupants.

The successful application of GLI and SfM photogrammetry in this context demonstrates the power and precision of UAV-based remote sensing techniques in urban green space assessment. Unlike traditional methods, which may be time-consuming and limited in scope, UAV technology allows for rapid, comprehensive, and accurate data collection over large areas. This capability is particularly valuable in urban environments, where the need for efficient and effective green space management is paramount.

In conclusion, the application of GLI and S*f*M photogrammetry in assessing the green spaces of Harran University Osmanbey Campus has not only provided valuable data on the current state of the campus's environment but also highlighted the potential of UAV-based technologies in supporting urban sustainability initiatives. With a GSR of 18.97%, the campus stands as a testament to the importance of integrating advanced remote sensing techniques into the management of urban green spaces, setting a standard that can be emulated in other urban contexts to foster ecological well-being and enhance the quality of life for urban residents.

Acknowledgement

Part of this work was presented at the AED-9 symposium. I would like to thank Nizar Polat for his contributions.

Author contributions

Seyma Akca: Writing-Original draft preparation, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The author declare no conflicts of interest.

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