THE FUTURE OF CITIES:

LANDSCAPE, PLANNING AND DESIGN



Editors
Mert ÇAKIR
Halime GÖZLÜKAYA

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PREFACE

As cities around the world confront unprecedented social, environmental, and technological challenges, the disciplines of architecture, landscape, and urban planning continue to redefine the way we envision our collective future. ***'The Future of Cities: Landscape, Planning and Architecture'*** brings together a diverse collection of studies that explore innovative approaches to designing, managing, and sustaining urban environments in a rapidly changing world.

The chapters in this volume present a wide spectrum of perspectives—from the use of remote sensing and smart city solutions to the conservation of cultural landscapes and the rethinking of traditional materials. Together, these contributions reflect an ongoing dialogue among researchers and practitioners committed to creating more resilient, inclusive, and environmentally responsive cities.

We would like to extend our sincere appreciation to all authors and reviewers whose scholarly efforts have enriched this book. Our deepest gratitude goes to Prof. Dr. Atila Gül, Coordinator of the Architectural Sciences Book Series, for his invaluable guidance, encouragement, and steadfast support throughout the publication process. We also thank the publishing team for their collaboration and professionalism.

We hope that this book serves as an inspiration for academics, professionals, and students dedicated to shaping sustainable and livable cities for generations to come.

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November 5, 2025

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The Role of Spectral Indices in Identifying Green Spaces for Urban and Landscape Planning: A Remote Sensing-Based Approach

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1. Introduction

In today's world, due to increasing population, rapid and unplanned urbanization, the expansion of impervious surfaces, and other anthropogenic pressures, natural and semi-natural areas are undergoing a significant transformation (Zeng, Yang, & Sarker, 2022a). This transformation directly affects the quantity and distribution of urban green spaces and, consequently, has substantial implications for ecological balance, ecological sustainability, climate change, and urban aesthetics (Puplampu & Boafo, 2021; Selim, Eyileten & Karakuş, 2023a). Urban green spaces are not merely aesthetic or recreational elements; they also serve multiple critical functions such as acting as carbon sinks, filtering noise and air pollution, mitigating the urban heat island effect, regulating thermal comfort, and supporting biodiversity (Semeraro, Scarano, Buccolieri, Santino, & Aarrevaara, 2021; Karakuş et al., 2024; Çakir & Gülsoy, 2025). Therefore, the accurate identification, monitoring, and planning of green spaces within urban and landscape planning processes are essential for achieving sustainable urban development (Kowe, Mutanga, & Dube, 2021; Halecki, Stachura, Fudała, Stec, & Kuboń, 2023).

In the identification and monitoring of urban green spaces, remote sensing technologies have emerged as a prominent and increasingly popular tool in recent years, particularly in terms of spatial data production, management, and analysis (Bai, Li, Guo, Chen, & Luo, 2022; Neyns & Canters, 2022). Advances in satellite imaging systems and high-resolution sensor technologies have enabled the analysis of urban areas with high accuracy, low cost, and in a short period of time (Das & Angadi, 2022).

These developments have significantly enhanced the importance of remote sensing technologies, especially for the detection and analysis of vegetation cover. The availability of more spectral bands through advanced sensors allows for the more precise identification not only of green areas but also of various green infrastructure components such as urban agricultural zones, roadside and median strip plantings, green roofs, parks, and gardens (Shahtahmassebi et al., 2022; Li, Taubenboeck, & Zhu, 2025). In this context, the use of vegetation indices—a key component of remote sensing technologies—has become increasingly prominent. These indices enable the rapid and accurate detection of green spaces, offering significant advantages in terms of time, cost, and labour efficiency (Gupta, Kumar, Pathan, & Sharma, 2012; Chen et al., 2022).

Vegetation indices are mathematical indicators calculated by ratioing reflectance values from different electromagnetic bands. These indices are defined as spectral transformations of two or more bands from remote sensing imagery, designed to enhance the contribution of vegetation characteristics and to enable reliable spatial and temporal comparisons of photosynthetic activity and biophysical changes (Bannari, Morin, Bonn, & Huete, 1995; Xue & Su, 2017; Radočaj, Šiljeg, Marinović, & Jurišić, 2023). Additionally, these indices can indirectly reflect properties such as vegetation density, health, and moisture content (Kureel, Sarup, Matin, Goswami, & Kureel, 2022; Chowdhury et al., 2024). In particular, the near-infrared (NIR) and red bands are widely used to assess the photosynthetic activity of plant tissues. Moreover, other bands such as shortwave infrared (SWIR), blue, green, and red-edge are also utilized to highlight various characteristics of green spaces (Zeng et al., 2022b; Zhu

& Guo, 2024). For instance, different mathematical combinations of these bands are effectively used in the detection of vegetation health (Haque et al., 2024), nitrogen content (Fan et al., 2022), water stress (Zhang et al., 2021a), drought (Sang et al., 2021), vegetation density (Liu et al., 2024), chlorophyll concentration (Gao et al., 2024), and similar features. In this context, it is evident that the performance of vegetation indices varies depending on different spatial, environmental, and physical conditions.

At this point, the spatial heterogeneity inherent in urban areas emerges as a significant factor that directly influences the performance of vegetation indices. Diverse urban fabrics—such as high-density residential zones, industrial areas, mixed-use developments, green spaces of varying densities, and transportation networks—exhibit considerable variation in surface reflectance. Buildings, roof types, road surfaces, soil characteristics, and other artificial elements affect the accuracy of vegetation detection using spectral indices (Zeng et al., 2022b). Therefore, selecting spectral indices that are appropriate for the physical and structural characteristics of the study area is crucial for ensuring the reliability of the analysis.

The primary aim of this study is to comparatively evaluate the effectiveness of various commonly used vegetation indices in the detection of urban green spaces, with the goal of providing a practical guide for their application in urban and landscape planning processes. In doing so, it seeks to assist planners, landscape architects, and decision-makers in selecting the most appropriate index based on the physical characteristics of the area, vegetation density, and land use type.

Furthermore, the study aims to contribute to the enhancement of spatial decision support systems, the rationalization of green infrastructure planning, and the integration of nature-based solutions. It is also anticipated that such analyses could offer tangible benefits for strategic planning efforts by central and local governments—such as identifying city-wide green space needs, planning ecological corridors, developing climate adaptation policies, and increasing urban resilience.

Ultimately, advancements in remote sensing technologies and the diversification of spectral indices are paving the way for more data-driven, transparent, and evidence-based decision-making processes in urban green space planning. The framework proposed in this study serves as a comprehensive reference for identifying which spectral indices are most frequently used in different urban fabric types and for determining the most suitable index under varying conditions. In this way, the study aims to offer a valuable resource that provides concrete contributions to planning disciplines and public administration in the pursuit of building sustainable cities.

2. Functions of Urban Green Spaces and Their Importance in Planning Disciplines

Urban areas are undergoing a significant transformation due to various socio-cultural and economic dynamics. In this process, a noticeable decline in natural and semi-natural areas, an increase in impervious surfaces, and the disruption of ecosystem services have been observed (Semeraro et al., 2021). In this context, urban green spaces stand out not only for their social, psychological, and aesthetic functions but also for their ecological, economic, and health-related benefits (Breuste

Schnellinger, Qureshi, & Faggi., 2013). Therefore, they should be regarded as planning components of strategic importance for urban sustainability.

From an ecological perspective, urban green spaces play vital roles such as improving air quality, supporting carbon sequestration, mitigating the urban heat island effect, preserving biodiversity, and facilitating water management, thereby contributing significantly to ecosystem services (Tuğluer & Çakır, 2021; Jabbar, Yusoff, & Shafie, 2022; Selim, Eyileten, & Karakuş, 2023b; Olgun et al., 2025). Vegetation helps regulate temperatures through evapotranspiration and shading, while also absorbing rainwater and reducing flood risk (Schuch, Serrao-Neumann, Morgan, & Choy, 2017; Çakır &Tuğluer 2019).

On the social level, green spaces provide environments that positively impact the physical and mental health of urban residents. By enabling recreational activities, promoting social interaction, and fostering community cohesion, they reinforce their indispensable role in urban life (Zhou & Parves Rana, 2012). Furthermore, their economic benefits—such as increasing property values and enhancing tourism potential—should not be overlooked (Zhang et al., 2021b).

Considering all these functions, the role of urban planning and landscape planning disciplines in the context of green spaces becomes increasingly significant. The planning process aims to balance spatial justice, ecological integrity, and social well-being by determining the distribution, accessibility, quantity, and quality of green spaces within the urban fabric (Eyileten, Esendağlı, & Selim, 2022). Moreover, the development of green infrastructure solutions tailored to different urban textures enhances the

contextual sensitivity of planning efforts (Selim, 2021). The integration of green spaces into planning not only addresses current needs but also lays the foundation for strategic actions that can improve urban resilience against future environmental risks (Halecki et al., 2023).

From a sustainability perspective, urban green spaces encompass environmental, social, and economic dimensions. Their environmental sustainability functions include conserving natural resources, maintaining ecosystem services, and contributing to climate change mitigation (Jennings, Larson, & Yun, 2016; Tuğluer & Çakır, 2019). In terms of social sustainability, equitable access to green spaces, protection of public health, and the promotion of social inclusion are key aspects (Teimouri, Karuppannan, Sivam, & Gu, 2019). Economic sustainability, on the other hand, can be assessed through the direct and indirect economic benefits provided by green spaces, as well as the balanced management of their maintenance and operational costs (Choumert & Salanié, 2008).

Recent scientific studies have clearly demonstrated the multifunctional roles of urban green spaces and their significance in sustainable urban development (Liu, Li, Qiu, & Liu, 2023). Numerous studies in the literature argue that, rather than focusing solely on the quantity of green spaces, greater emphasis should be placed on their quality, accessibility, and spatial distribution for a more effective planning approach (Olgun, Kahraman & Karakuş, 2022). Therefore, it is essential for urban and landscape planning disciplines to consider this multidimensional structure and integrate urban green spaces into spatial decision-making processes. This integration plays a critical role in building sustainable, resilient, and livable cities.

The initial step in incorporating urban green spaces into spatial planning processes is the accurate identification of these spaces within the complex urban fabric. While traditional methods are often time-consuming, labour-intensive, and costly, the rapid advancement of modern technologies has greatly facilitated the detection of green spaces. At this point, remote sensing (RS) and geographic information systems (GIS) offer significant advantages for the fast, accurate, and practical identification of urban green spaces.

3. Remote Sensing-Based Methods for Identifying Urban Green Spaces

Remote sensing technologies for detecting urban green spaces are increasingly supported by advanced and automated methods. Among these, machine learning (ML), deep learning (DL), artificial neural networks (ANN), and hybrid classification techniques stand out (Shi, Liu, Marinoni, & Liu, 2022; Hu et al., 2024; Ganjirad, Delavar, Bagheri & Azizi, 2025; Huang et al., 2025). These methods enable pixel-level analysis of satellite imagery or aerial photographs, allowing for more accurate discrimination of green spaces compared to traditional classification approaches (Xu et al., 2020).

Machine learning-based approaches are among the most commonly used methods for remote sensing data analysis. Advanced classifiers such as Random Forest (RF), Support Vector Machine (SVM), Gradient Boosting algorithms, and particularly LightGBM effectively classify green spaces by utilizing various spectral bands, texture features, and geometric variables. The main advantage of these methods lies in their ability to analyze heterogeneous land cover in high-resolution imagery in detail and

to improve accuracy by processing a large number of variables (Rustamov, Rustamov & Zaki, 2023). For instance, by combining data from satellites such as GF-2 (Gaofen-2), and Sentinel-2, the integration of multispectral and multi-resolution datasets enables the accurate classification of small-scale green spaces.

Artificial neural networks and deep learning techniques have also gained significant importance in recent years for the detection of urban green spaces. Architectures such as Convolutional Neural Networks (CNN), U-Net, DeepLab, and SegNet enable the automatic identification of green spaces through semantic segmentation of images (Huerta et al., 2021). These methods allow for the classification of green spaces not only based on spectral information but also by utilizing spatial patterns and contextual features. When applied to high-resolution imagery, they can accurately detect detailed green elements such as green roofs, small parks, or street tree plantings (Moreno-Armendáriz et al., 2019). However, these techniques also have certain limitations, including high computational requirements and sensitivity to training datasets.

On the other hand, hybrid approaches that combine different methods have also been favoured in many studies. For example, basic classification outputs derived from spectral data are reanalyzed using machine learning or deep learning models to obtain more specialized results (Wang et al., 2023). These hybrid systems provide more accurate and generalizable outcomes within the complex structure of urban fabric and offer the advantage of adapting to different urban typologies. Such multi-layered analyses in the field of remote sensing hold significant potential to be

employed as decision support mechanisms in urban planning and landscape management processes.

4. Advantages of Spectral Indices over Other RS Methods for Green Spaces Detection

Although the aforementioned remote sensing methods possess the capability to detect green spaces in urban fabric with sufficient accuracy, they also present certain challenges. Firstly, these approaches require labelled training data (ground-truth); the preparation of data, class sampling, and creation of validation sets are time-consuming and demand expertise (Hu et al., 2024). Such data vary depending on the heterogeneous nature of the urban fabric, which limits the model's generalizability. Additionally, the high number of spectral bands, high-resolution imagery, and big data processes pose disadvantages in terms of cost and processing time. The complexity of the algorithms also complicates the decision-making process. Non-spectral methods may be more sensitive to external factors such as shading, atmospheric distortions, and sensor angle. Moreover, small green spaces or micro-scale vegetation may not be accurately detected in low-resolution imagery (Shahtahmassebi et al., 2021).

Spectral indices often require less data pre-processing. They have a lower demand for extensive labelled datasets for algorithm training. Spectral indices are also well-suited for change detection over large areas and time series analyses; by calculating index values from numerous satellite images, the spatial distribution, density, and temporal changes of green spaces can be monitored (Dutta, Rahman, Paul, & Kundu, 2022). This is particularly advantageous for tracking trends and developing long-term

decision support systems without the need to retrain classification models (Huete, 2012). Additionally, spectral indices offer relative simplicity, interpretability, and low computational resource requirements (Huang Tang, Hupy, Wang, & Shao, 2021). Compared to machine learning and deep learning methods, they are more practical in terms of hardware and processing power. This advantage is especially important in contexts where data infrastructure and technical capacity are limited.

5. Commonly Used Spectral Indices for Identifying Urban Green Spaces

The literature reveals that numerous spectral indices are used for the detection of urban green spaces. Among these are the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Soil-Adjusted Vegetation Index (SAVI), Modified SAVI (mSAVI), Green Normalized Difference Vegetation Index (gNDVI), Ratio Vegetation Index (RVI), Difference Vegetation Index (DVI), Transformed Vegetation Index (TVI), Perpendicular Vegetation Index (PVI), Atmospherically Resistant Vegetation Index (ARVI), Soil-Adjusted and Atmospherically Resistant Vegetation Index (SARVI), Normalized Difference Water Index (NDWI), Normalized Difference Moisture Index (NDMI), Normalized Difference Infrared Index (NDII), Global Environmental Monitoring Index (GEMI), Soil and Vegetation Index (SVI), Chlorophyll Index Green (CIgreen), Chlorophyll Index Red Edge (CIrededge), Weighted Difference Vegetation Index (WDVI), and Modified Chlorophyll Absorption in Reflectance Index (mCARI), among many others (Xue & Su, 2017). According to the IDB website, a total of 519 spectral indices related to vegetation have been defined, along with academic articles utilizing these

indices (IDB, 2025). Each of these indices emphasizes different characteristics of vegetation in classification. The sensors used, the number of bands, and their spectral ranges enable the extraction of various vegetation-related information. Table 1 lists commonly used vegetation indices in the literature that offer ease of use, along with their formulas, advantages, and disadvantages.

Table 1. Information on Vegetation Indices Used for the Detection of Urban Green Spaces (Xue & Su, 2017; IDB, 2025).

Spectral Indices	Formula	Advantages	Disadvantages
NDVI (Normalized Difference Vegetatic Index)	(NIR - Red) / (NIR + Red)	Accurate and computationally simple methods for vegetation density estimation	In urban areas, soil and built structures can have an impact, and vegetation detection may be affected by shadows.
EVI (Enhanced Vegetation Index)	2.5 × (NIR - Red) / (NIR + 6×Red - 7.5×Blue + 1)	Less affected by atmospheric effects-more accurate in dense vegetation cover	More complex formula-requires blue band
SAVI (Soil Adjusted Vegetation Index)	((NIR - Red) / (NIR + Red + L)) × (1 + L) (L genelde 0.5)	Reduces soil influence — advantageous in sparse vegetation	The selection of the L constant can be subjective
GNDVI (Green Normalized Difference Vegetation Index)	(NIR - Green) / (NIR + Green)	More sensitive to vegetation health — can perform better than NDVI	In some sensors, the quality of the green band may be low
VARI (Visible Atmospherically Resistant Index)	(Green - Red) / (Green + Red - Blue)	Operates using only visible bands	Accuracy may decrease without NIR-susceptible to shadows
mSAVI (Modified Soil Adjusted Vegetation Index)	[2×NIR + 1 - √((2×NIR + 1)² - 8×(NIR - Red))] / 2	It is an improved version of SAVI and effectively reduces soil influence	The calculation is more complex
ARVI (Atmospherically Resistant Vegetation Index)	(NIR - (2×Red - Blue)) / (NIR + (2×Red + Blue))	Less affected by atmospheric effects	Dependent on the sensitivity of the blue band
NDMI (Normalized Difference Moisture Index)	(NIR - SWIR) / (NIR + SWIR)	Provides information about plant water content — suitable for drought monitoring	More suitable for assessing vegetation health rather than directly detecting the presence of green areas
TCI-Green (Tasseled Cap Index - Green Component)	Obtained from the Tasseled Cap transformation (satellite-specific coefficients)	The green component is prominent, enabling detailed analysis in urban areas	There are different formulas depending on the satellite, requiring preprocessing.

As seen in the Table 1, these spectral indices—developed primarily to highlight different characteristics of green spaces—essentially focus on detecting green areas. However, in urban environments, researchers must determine the appropriate index selection based on the environmental, structural, and surface characteristics of the study area. Factors such as image resolution, presence of water and moisture, shadow effects, building density, vegetation density, species diversity, and others serve as key criteria guiding researchers in choosing the most suitable indices. Figure 1 illustrates maps of some vegetation indices used for identifying green spaces within a complex urban fabric.

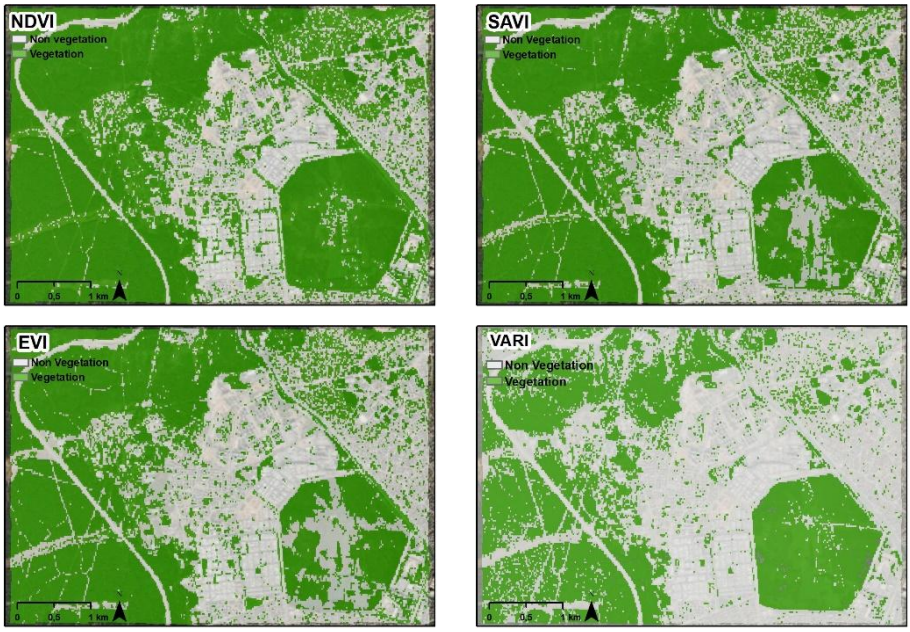


Figure 1. Maps Generated Using Selected Vegetation Indices in a Complex Urban Fabric.

In Figure 1, vegetation maps of the same study area were produced using the NDVI, SAVI, EVI, and VARI indices to classify green spaces. The differences between the EVI index, which reduces atmospheric effects,

and the NDVI index, noted for its good performance in dense vegetation, are visually distinguishable on the maps. Similarly, the SAVI index, which reduces soil effects and is advantageous in sparse vegetation, appears to yield better results in this study area compared to the VARI index, which is calculated using only visible bands.

Based on these results, the effective use of spectral indices in the detection of urban green spaces depends not only on numerical data analysis but also on an accurate understanding of the physical and spatial characteristics of the study area. Urban surface cover is highly heterogeneous; green spaces can be interwoven with concrete, asphalt, and shaded structures. This situation may reduce the performance of some indices while making others more advantageous. For example, if the proportion of bare soil is high, indices like SAVI or mSAVI are more suitable, whereas in areas with dense shading and structural complexity, indices such as EVI that reduce atmospheric effects are preferable. Therefore, researchers need to conduct field observations and on-site investigations to accurately characterize land features. Strong field observation skills directly influence the success of index selection.

6. Conclusion and Suggestions

In this study, commonly used spectral vegetation indices for detecting urban green spaces through remote sensing techniques were examined, and their comparative advantages and disadvantages were evaluated. Most spectral indices can characterize vegetation based on different reflectance properties; however, each index demonstrates varying levels of performance, especially in heterogeneous environments such as urban areas. Therefore, the selection of an appropriate index requires not only

technical considerations but also a decision-making process grounded in the characteristics of the study area and the landscape pattern.

Urban areas are complex environments where natural and artificial surfaces intermingle, exhibiting high variability in reflectance and frequent shading effects. In this context, although the Normalized Difference Vegetation Index (NDVI) is a widely used and practical index, it may be influenced by atmospheric effects and soil reflectance in densely built-up areas. Under such conditions, the performance of indices such as the Enhanced Vegetation Index (EVI), Soil-Adjusted Vegetation Index (SAVI), and Modified SAVI (mSAVI) should be evaluated and compared. Moreover, indices that consider water presence and moisture conditions, such as the Normalized Difference Water Index (NDWI) and Normalized Difference Moisture Index (NDMI), are particularly important for detecting green spaces with water availability. For assessing vegetation health, the performance of indices like the Chlorophyll Index Green (CIgreen) and EVI should also be specifically evaluated.

One of the key findings of this study is the decisive influence of the study area's characteristics on the selection of spectral indices. Factors such as vegetation density, the ratio of soil to concrete surfaces, shadow effects, atmospheric conditions, and image resolution directly impact the accuracy of the chosen index. Therefore, instead of a universal standard, a context-sensitive approach tailored to the local environment should be adopted when using spectral indices.

Moreover, the researcher’s strong land survey skills play a critical role in interpreting satellite data. Land surveys and ground control points help validate the results obtained from remote sensing data and prevent

misclassifications. Hence, conducting an on-site examination of the study area and analyzing its physical and environmental features prior to index selection is of great importance.

This study is considered to offer direct practical contributions, especially for urban planners, landscape architects, and policymakers. Working with accurate data is fundamental for the protection, development, and sustainable management of green spaces in urban planning, forming the basis for sound decision-making processes. Proper use of spectral indices serves as a vital tool both for mapping existing green infrastructure and for long-term monitoring efforts.

In conclusion, although advances in remote sensing technologies have made spectral indices more accessible and widespread, the appropriate selection of indices should be shaped by the specific characteristics of the study area, data properties, and the researcher's observational expertise. In this regard, the present study provides valuable guidance for both academic researchers and practitioners.

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This book chapter was co-authored by two authors who contributed equally to the work, and there are no conflicts of interest to declare.

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