Review

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Advances and Challenges in GIS-Based Assessment of Urban Green Infrastructure: A Systematic Review (2020–2024)

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Advances and Challenges in GIS-Based Assessment of Urban Green Infrastructure: A Systematic Review (2020–2024)

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Abstract

Urban green infrastructure (UGI) is critical for improving ecological resilience, public health, and social equity in the face of increasing urbanization. Geographic Information Systems (GIS) are critical tools for evaluating the spatial, environmental, and social dimensions of Urban Green Infrastructure. This systematic review brings together empirical GIS-based evaluations of UGI published between 2020 and 2024, highlighting methodological innovations, data sources, analytical frameworks, and persisting issues. We identify trends using remote sensing, machine learning, and multi-criteria decision analysis to improve green space accessibility, ecosystem service provision, and urban resilience. Despite increased interdisciplinarity and technological innovation, shortcomings remain in standardized evaluation procedures, geographic representation, and the incorporation of social justice factors. Our findings underscore the importance of standardized frameworks and better participatory GIS approaches for promoting sustainable and equitable urban development. This paper provides a fundamental synthesis for researchers, planners, and politicians who want to improve GIS-based urban greening programs.

Keywords: urban green infrastructure; Geographic Information Systems (GIS); remote sensing; spatial analysis; urban sustainability; ecosystem services; multi-criteria decision analysis; social equity; urban resilience

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Introduction

Urbanization has become a critical phenomenon of the twenty-first century, transforming cities into primary drivers of economic growth, innovation, and cultural exchange (United Nations, 2015, as cited in Mironova, 2021; Bai et al., 2022). This rapid urbanization has increased pressure on natural ecosystems and created important challenges for social justice, environmental sustainability, and public health (Mironova, 2021; Pouya & Aghlmand, 2022; Rachid et al., 2024). International policy frameworks, particularly the Sustainable Development Goals (SDGs), particularly SDG 11, have emphasized the importance of building sustainable cities and communities as key components of global development agendas (United Nations, 2015, cited in Mironova, 2021; Bai et al., 2022).

Green infrastructure (GI) has emerged as an important approach for navigating the complex link between urban growth and environmental conservation. Green Infrastructure (GI) refers to networks of natural and semi-natural places such as parks, green roofs, urban forests, and wetlands that collectively provide ecosystem services, climate management, and social well-being (Buchavyi et al., 2023; Mobarak et al., 2022). Contemporary urban design increasingly prioritizes green infrastructure, recognizing its importance in improving urban resilience, biodiversity, recreational opportunities, and overall quality of life (Hoeben & Posch, 2021; Huang et al., 2023). The literature emphasizes the multifunctionality of green infrastructure (GI), highlighting the integration of ecological, cultural, and economic services, as well as the importance of connectivity, size, and interdisciplinary collaboration in achieving sustainable urban outcomes (Waheeb et al., 2023; Bai et al., 2022).

Recent advances in GIS technology have transformed the assessment and management of urban green infrastructure. Geographic Information Systems (GIS) are critical tools for assessing spatial patterns, monitoring ecological processes, and enabling data-driven decision-making in urban planning (Mohammed & Hammo, 2023; Xu et al., 2020). GIS allows for the integration of remote sensing data, stakeholder contributions, and spatial indicators to evaluate green space accessibility, quality, and susceptibility to environmental threats (Vîlcea & ůoșea, 2020; Huang et al., 2023). As a result, GIS-based analysis improves scientific understanding of urban ecosystems and informs policy formulation and practical strategies for sustainable urban development (Ghasemi et al., 2022).

Despite the acknowledged importance of Geographic Information (GI) and the increasing complexity of Geographic Information Systems (GIS)-based approaches, some significant gaps remain in the current study domain. Significant debate exists across academic, policy, and practical domains about the precise definition, classification, and standardized evaluation of GI (Waheeb et al., 2023). The lack of consensus has hampered the development of a consistent methodology, reducing study comparability and the adoption of best practices (Ghasemi et al., 2022).

Second, while the theoretical foundations of green infrastructure design are well defined, significant empirical guidance for the practical application of GI in real-world geographical locations remains insufficient (Mironova, 2021). Urban planning is rapidly changing because of emerging technologies such as big data analytics and artificial intelligence, which bring new potential while also increasing complexity and barriers to data integration (Yang, 2024). Systematic evaluations of urban sustainability often focus on distant sensing or ecological characteristics, without considering social, aesthetic, and equity concerns (Rodríguez-Espinosa et al., 2020; Hoeben & Posch, 2021).

Furthermore, a large proportion of the research is geographically dispersed, with significant heterogeneity in the types of gastrointestinal indicators assessed, data sources used, and analytical frameworks used (Buchavyi et al., 2023; Mohammed & Hammo, 2023). Limited studies have provided a comprehensive synthesis that spans multiple disciplines, geographies, and methodological developments. As a result, there is an urgent need for a current, thorough evaluation that outlines current accomplishments, identifies long-standing challenges, and explains prospects in GIS-based GI assessment.

This review synthesizes recent research on GIS-based evaluations of urban green infrastructure to overcome the limitations noted above. The goal is to clarify existing methodology, data sources, analytical frameworks, and empirical findings, while focusing on developing trends and persisting concerns. The scope comprises peer-reviewed empirical studies published between 2020 and 2024 on various urban contexts, green infrastructure typologies, and geographic information system applications. The complete breadth of green infrastructure assessment includes research on accessibility, ecosystem services, resilience, social equity, aesthetic values, and policy implications.

The specified goals are as follows.

1. Identify and categorize the major subjects, geographical areas, and types of urban green infrastructure investigated in GIS-based assessment studies.

2. Evaluate the data sources, analytical methodologies, and validation approaches used in contemporary research.

3. Evaluate progress and obstacles in interdisciplinary integration, considering ecological, social, and economic considerations.

4. To highlight best practices and persistent shortcomings in empirical execution, standardization, and policy significance.

5. To identify future research and practice directions, emphasizing methodological rigor, inclusivity, and practical recommendations for sustainable urban development.

This review aims to provide a consistent foundation for advancing academic research and practical innovation in the planning, assessment, and optimization of urban green infrastructure using GIS.

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Methods

A comprehensive analysis was done to incorporate the most recent advances in the assessment of urban green infrastructure (UGI) and its relationship to health outcomes, with a focus on the use of Geographic Information Systems (GIS). The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standards (Moher et al., 2009), ensuring methodological precision and transparency.

A complete analysis of the literature focusing on peer-reviewed studies published between January 1, 2020, and June 30, 2024. The Web of Science (WOS) databases Scopus, Science Citation Index (SCI), and Social Science Citation Index (SSCI) provide comprehensive disciplinary coverage and rigorous quality control (Falagas et al., 2008; Mongeon & Paul-Hus, 2016; Martín-Martín et al., 2018). To improve the retrieval of relevant research, search parameters were coupled using Boolean operators, including versions of "urban greening," "green infrastructure," "green space," "GIS," and "health" or "well-being."

The following criteria were used to select studies: (a) they were published in English; (b) they were published in peer-reviewed journals; (c) they included empirical research on urban green infrastructure (UGI) within urban environments; and (d) they used Geographic Information Systems (GIS) for assessment or analysis. Publications that were redundant, irrelevant to urban green infrastructure, had no practical application (i.e., theoretical initiatives), or were non-peer-reviewed sources (such as conference proceedings and book chapters) were rejected.

Two reviewers separately reviewed the relevancy and eligibility of all title and abstract submissions. The inclusion criteria were then utilized to assess full-text papers. To settle disagreements in article selection or evaluation, consensus was used; if this failed, a third reviewer advocated arbitration. This multi-phase procedure decreased selection bias and increased reliability.

Each study provided demographic information, the type of greening intervention, a GIS approach, health results, and major conclusions. Common themes, analytical methodologies, and growing challenges in GIS-based UGI research were discovered using thematic analysis to integrate findings from multiple studies (Kitchenham & Charters, 2007). This meta-analysis considered both quantitative variables (e.g., NDVI for vegetation, per capita green space, accessibility assessments) and qualitative features (e.g., perceived benefits and policy outcomes).

The methodological quality of the selected studies was assessed using a predetermined set of criteria, which included the specificity and transparency of GIS tools, the clarity of study objectives, the reproducibility of methods, and proof of empirical assessment with optimization recommendations. Quality assessments were carried out independently by two evaluators, with disagreements settled through discussion or third-party mediation. Each criterion was evaluated on a three-tier scale (completely matched, slightly matched, and unmatched).

This review recognizes various limitations, including language and publishing bias, because it exclusively examines peer-reviewed papers in English. The absence of gray literature may limit the generalizability of the conclusions. Furthermore, differences in GIS data sources and analytical methodologies between research may have altered results integration.

This methodology combines automated database queries with manual evaluation to capture current research trends and methodological methods in GIS-based urban greening assessment. This supports strong findings and guides future study and practice in sustainable urban development (Falagas et al., 2008; Mongeon & Paul-Hus, 2016; Martín-Martín et al., 2018; Kitchenham & Charters, 2007; Moher et al., 2009).

Author(s) & Year	**Geographic Location**	**UGI Type Studied**	**GIS Methods Used**	**Key Outcomes/Findings**	**Data Sources**
Buchavyi et al. (2023)	Dnipro, Ukraine	Urban green space percentage	NDVI, Satellite imagery, Field survey	Accurate mapping of green space boundaries; integration of multi-source data	Landsat, Sentinel, Google Earth, Field surveys
Mohammed & Hammo (2023)	Duhok City, Iraq	Urban parks	Satellite image classification, NDVI	Evaluation of park accessibility and green space quality	Satellite imagery, Google Earth, Field surveys
Ghasemi et al. (2022)	Tehran District 22, Iran	Accessibility to green spaces	Combined Compromise Solution (CoCoSo), GIS network analysis	Identified accessibility gaps and prioritized green space investments	Administrative records, Demographic data
Vîlcea & ůoșea (2020)	Craiova, Romania	Urban green space accessibility	Network analysis, Service area coverage	Highlighted spatial inequality and accessibility challenges	GIS datasets, Demographic data
Mobarak et al. (2022)	Al Baha region, Saudi Arabia	Parks and green corridors	Multi-Criteria Decision Analysis (AHP), GIS suitability mapping	Identified suitable areas for green infrastructure development	Governmental spatial data, Remote sensing

Author(s) & Year	Geographic Location	UGI Type Studied	GIS Methods Used	Key Outcomes/Findings	Data Sources
Rachid et al. (2024)	Nador City, Morocco	Carbon storage and urban greening	GIS integrated with InVEST model	Spatial prioritization for carbon sequestration and urban greening	Remote sensing, InVEST data
Hoeben & Posch (2021)	Graz, Austria	Green roofs	Standardized GIS approaches, Remote sensing	Assessed biodiversity and thermal regulation benefits	Remote sensing data
Waheeb et al. (2023)	Taif Province, Saudi Arabia	Green space infrastructure	GIS and Multi-Criteria Decision Analysis (MCDA)	Enhanced sustainable urban planning through prioritized green space allocation	Remote sensing, administrative data
Osseni et al. (2023)	Abomey-Calavi District, Benin	Urban green spaces	GIS-based multi-criteria Analysis	Selected suitable sites considering social, economic, environmental factors	Open-source GIS data, Census data
Zhang et al. (2024)	Suzhou, China	Visual assessment of historic green landmarks	GIS spatial analysis, Survey data	Integrated subjective and objective assessment of urban green aesthetics	GIS layers, Perception surveys

Thematic Quantitative Analysis and Results

Urban green infrastructure (UGI) is critical for ecological resilience, environmental equality, and public health in cities around the world. With urban populations expanding at previously unheard-of rates, it is becoming increasingly important to study, improve, and allocate green areas methodically (Hailemariam, 2021; Kim et al., 2021). The rapid expansion of urban infrastructure,

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combined with the difficulties of climate change and socioeconomic inequality, has increased planners and academics' responsibilities to develop feasible, scalable solutions for sustainable urban management.

Geographic information systems (GIS) play a critical role in the strategic development, analysis, and assessment of urban green infrastructure. The ability of GIS to methodically integrate a variety of datasets, including high-resolution satellite imagery, in-depth field surveys, demographic data, and real-time environmental sensor data, has enabled multi-scale, interdisciplinary assessments that support UGI policy and intervention.

The following sections investigate the quantitative findings and thematic concerns of modern GIS-based UGI research, drawing on case studies, systematic reviews, and an emerging body of international literature.

Remote sensing data and spatial analysis methods form the basis of modern UGI quantification. Landsat, Sentinel, and commercial companies like WorldView and QuickBird use multispectral and hyperspectral data, as well as vegetation indices like NDVI, to identify, characterize, and quantify the quantity and quality of urban green cover (Buchavyi et al., 2023; Mohammed & Hammo, 2023). With the use of these IDs, researchers can now monitor changes in urban vegetation with temporal precision that was previously difficult to achieve using conventional methodologies.

Land cover classification and the construction of green infrastructure typologies have grown easier thanks to advances in supervised classification approaches such as object-based image analysis and support vector machines. Integrating these methodologies into GIS systems allows for the creation of time-series data and complex, spatially explicit maps that illustrate both dynamic trends and geographic variability.

Data fusion has many applications than just satellite imagery. Nowadays, remotely sensed data is combined with administrative records, population density grids, building footprints, cadastral boundaries, field survey data, and other environmental data such as soil maps, digital elevation models (DEMs), and climate datasets (Hailemariam, 2021; Huang et al., 2023). Well-researched, contextually nuanced, and geographically accurate UGI assessments highlight the complexities of real-world urban ecosystems.

GIS Data Sources	Frequency of Use (No. of Studies)	Percentage (%)	Description/Examples
Remote Sensing Imagery (e.g., Landsat, Sentinel, QuickBird)	15	75%	Multispectral/hyperspectral data for vegetation mapping and land cover classification
NDVI and Vegetation Indices	12	60%	Normalized Difference Vegetation Index to quantify green cover density
Field Surveys / Ground Truth	8	40%	Used for validation of remote sensing data and accuracy assessment

GIS Data Sources	Frequency of Use (No. of Studies)	Percentage (%)	Description/Examples
LiDAR	3	15%	High-resolution elevation data for 3D structure and canopy analysis
Crowdsourced / Social Data	4	20%	Public participation GIS (PPGIS), perception surveys, and social media data
Governmental Administrative Data	10	50%	Demographic, land use, and cadastral datasets for spatial context

Researchers in Dnipro and Duhok City used NDVI-derived metrics, field surveys, and Google Earth to confirm the accuracy of remotely sensed green space boundaries (Buchavyi et al., 2023; Mohammed & Hammo, 2023). the integration of several data sources to provide a more comprehensive and reproducible study of the dynamics, quality, and distribution of change in urban green infrastructure (UGI).

The history of GIS-based urban green infrastructure assessment highlights significant methodological advances in urban ecology, planning, and decision science. Early GIS applications for green space research relied on descriptive mapping and basic spatial statistics. The discipline has seen substantial advancements in sophisticated quantitative research tools such as statistical modeling, machine learning, spatial optimization, and participatory frameworks (Bai et al., 2022).

Important contemporary trends include:

• Automated classification and change detection: Two machine learning techniques, support vector machines and neural networks, allow for the identification and tracking of green space classifications and modification trends in real-time or near-real-time (Pouya & Aghlmand, 2022; Bai et al., 2022).

The availability of urban big data, particularly crowdsourced environmental data and open-source GIS datasets, has improved the geographical and thematic resolution of UGI research.

• Scenario modeling and simulation: In the context of future land use, urban expansion, and climate change scenarios, Geographic Information Systems (GIS)-based models are increasingly being used to predict how planning decisions or environmental policies will affect the distribution and efficacy of urban green infrastructure (UGI) (Kim et al., 2021; Waheeb et al., 2023).

Per capita green space metrics are often used in quantitative GIS assessments of urban green infrastructure to assess sustainability and quality of life (Huang et al., 2023; Ghasemi et al., 2022). This study uses green space polygons and high-resolution population distribution data to provide spatially disaggregated measurements at the neighborhood, district, and city levels.

These surveys frequently reveal significant discrepancies in access to green places. According to Vîlcea and ɘoşea (2020), wealthy or marginal areas have much more green space compared to densely populated urban areas that may not exceed international standards for per capita green space. The integration of demographic factors such as age distribution, income, and population vulnerability into localized indicators enables equity-focused evaluations that identify at-risk areas and lead targeted measures (Huang et al., 2023).

In addition to static assessments of green space levels, accessibility models and service area coverage indices are increasingly used in spatial equality research. Aside from distance, accessibility is determined by practical ease of access, which includes physical barriers, transit infrastructure, and urban design.

The Combined Compromise Solution (CoCoSo) method, which incorporates GIS, was used in Tehran District 22 to identify accessibility difficulties and prioritize spending on new green infrastructure (Ghasemi et al., 2022). Research undertaken in Craiova, Romania, underlined the need for better roads and larger park areas, utilizing network analysis to define accessibility borders and catchment regions (Vîlcea & ɵoşea, 2020).

Socioeconomic status, environmental concerns, public transportation accessibility, and walkability are frequently used when assessing spatial equality, resulting in profiles of full access and deprivation. These efforts promote environmental justice and help communities fulfill global criteria for equitable distribution of green spaces (such as WHO recommendations).

Complex network analysis modules in GIS systems simulate real-world traffic patterns, costs, and distances between residential communities and green space amenities (Yang, 2024). These models overcome the limitations of traditional Euclidean distance estimations by accounting for features such as road networks, barriers, terrain, and transportation infrastructure.

The accessibility indices, which include minimal trip duration, service area coverage, and cumulative opportunity measurements, identify areas where access is hampered by societal or structural impediments. A GIS-based network analysis revealed "green deserts" (areas functionally different from green spaces) and "green privilege" zones in highly populated urban areas of Asia and Africa, allowing for more complicated and contextually aware design solutions to be implemented.

GIS-based UGI planning typically requires reconciling opposing ecological, social, economic, and infrastructure demands across various urban contexts. Several Multi-Criteria Decision Analysis (MCDA) methodologies, notably the Analytical Hierarchy Process (AHP), have been widely used to deal with this complexity (Mobarak et al., 2022; Waheeb et al., 2023; Hailemariam, 2021).

MCDA/AHP frameworks help planners assess and prioritise the relative importance of elements like flood risk, population density, environmental sensitivity, access to public amenities, and the presence of vulnerable populations by combining a variety of quantitative and qualitative indicators. Decision support systems that use spatially explicit suitability or risk maps help with site selection, prioritization, and policy development (Hailemariam, 2021).

Researchers in Saudi Arabia and Benin employ AHP-based MCDA paired with GIS to identify the ideal locations for new parks or green corridors while considering social, economic, and environmental factors (Mobarak et al., 2022; Waheeb et al., 2023; Osseni et al., 2023).

Suitability mapping, which includes both Weighted Overlay Analysis (WOA) and Ordered Weighted Averaging (OWA), improves the consistency and transparency of green space design decisions. Mobarak et al. (2022) and Hailemariam (2021) demonstrated the effects of changing the weights or thresholds of critical components on the expected outcomes, demonstrating how these tactics aid in scenario comparison, stakeholder bargaining, and iterative planning.

Scenario modeling is a common technique for evaluating green infrastructure using GIS. To assess the implications for urban green infrastructure, connectivity, and resilience, urban planners simulate a variety of future scenarios, including population expansion, the effects of climate change, and changes to land use rules. Scenario-based approaches are critical for assessing plans under pressure and ensuring long-term viability.

Rodríguez-Espinosa et al. (2020) suggest incorporating local knowledge, stakeholder values, and resident perspectives into spatial design using participatory GIS methodologies. The qualitative data gathered through focus groups, perception surveys, and community mapping is spatially encoded and integrated into traditional geographic layers (Zhang et al., 2024).

Participatory initiatives make the construction of urban green infrastructure more legitimate and locally relevant. Rodríguez-Espinosa et al. (2020) suggest that qualitative indicators can help identify challenging targets, access constraints, and culturally significant green places. Stakeholder-driven evaluation makes it easier to solve problems and reach consensus on green infrastructure projects.

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Social inclusion is required for an equitable allocation of ecological infrastructure. Procedural equity and distributional equality are increasingly being investigated in GIS-based research, which focuses on the representation of varied perspectives and decision-making processes for urban green infrastructure. The evaluation of green space accessibility for low-income households, the elderly, and children emphasizes the need for more inclusive urban development while also highlighting long-standing inequities.

Because research shows that access to green spaces in urban contexts reduces risks to one's physical and mental well-being, particularly during emergencies like the COVID-19 pandemic, it is directly tied to health equity (Pouya & Aghlmand, 2022). enables urban inhabitants develop collaborative information via participatory GIS, resulting in both real and perceived benefits.

Geographic information systems are increasingly being used in Urban Green Infrastructure research to systematically assess and categorize the ecological benefits of urban green spaces. When ecosystem service models, such as InVEST, are spatially integrated, a variety of benefits, such as carbon sequestration, microclimate regulation, biodiversity conservation, stormwater management, air purification, pollution reduction, and recreational value, become more easily assessed.

Empirical case studies demonstrate the strategy's success. In Nador City, Morocco, the InVEST model was integrated with GIS to identify spatial patterns of carbon storage and prioritize urban greening places (Rachid et al., 2024). In Graz, Austria, the benefits of green roofs for biodiversity and thermal control were investigated using standardized approaches for various types of urban development.

Ecosystem service maps are vital for visualizing co-benefits, identifying trade-offs, and increasing the adaptability of urban green infrastructure (UGI).

Critical biological corridors that promote species migration and improve urban resilience are found through connection research using least-cost paths, gravity models, and network analysis inside GIS (Mirova, 2021). These models emphasize the importance of green spaces' size, connectedness, and spatial layout in preserving ecosystem function and biodiversity.

Intentional investments in green corridors could improve biological connectivity, increase pollinator populations, and reduce weather extremes, according to a GIS analysis of fragmented landscapes in Mediterranean and East Asian cities (Mironova, 2021; Wanghe et al., 2020).

Overall risk assessments are improved by including LiDAR, meteorological, hydrological, and social data layers into GIS, especially for environmental calamities such as flooding and heat stress (Xu et al., 2020; Bai et al., 2022). High-resolution risk maps make it easier to strategically allocate new green spaces to boost urban resilience while decreasing vulnerability.

Using geographic information system-based scenario modeling, Chinese researchers investigated how green infrastructure affects the risk of urban flooding. This method generates spatially explicit suggestions for implementing urban green infrastructure by combining topography, precipitation, land use, and expert opinions (Hailemariam, 2021; Osseni et al., 2023).

Methodological complexity and data integration capabilities illustrate GIS-based UGI research's expanding interdisciplinarity. Government data, academic research, commercial datasets, open-source geospatial data, and real-time environmental sensors are frequently used to build high-resolution analytical frameworks (Bai et al., 2022).

Using many data sources, including environmental sensor networks, social surveys, cadastral and infrastructure data, improves the validity and policy relevance of quantitative assessments of green infrastructure (Rodríguez-Espinosa et al., 2020).

Using sophisticated visualization tools makes it easier to transform complex spatial analyses into meaningful information. GIS platforms are progressively providing high-resolution mapping, interactive interfaces, and 3D modeling capabilities to better communicate results to a wide range of stakeholders, including planners, decision-makers, and the public.

Interactive suitability maps encourage transparency and flexibility in decision-making by allowing stakeholders to change planning criteria and evaluate outcomes in real time. Visualisations

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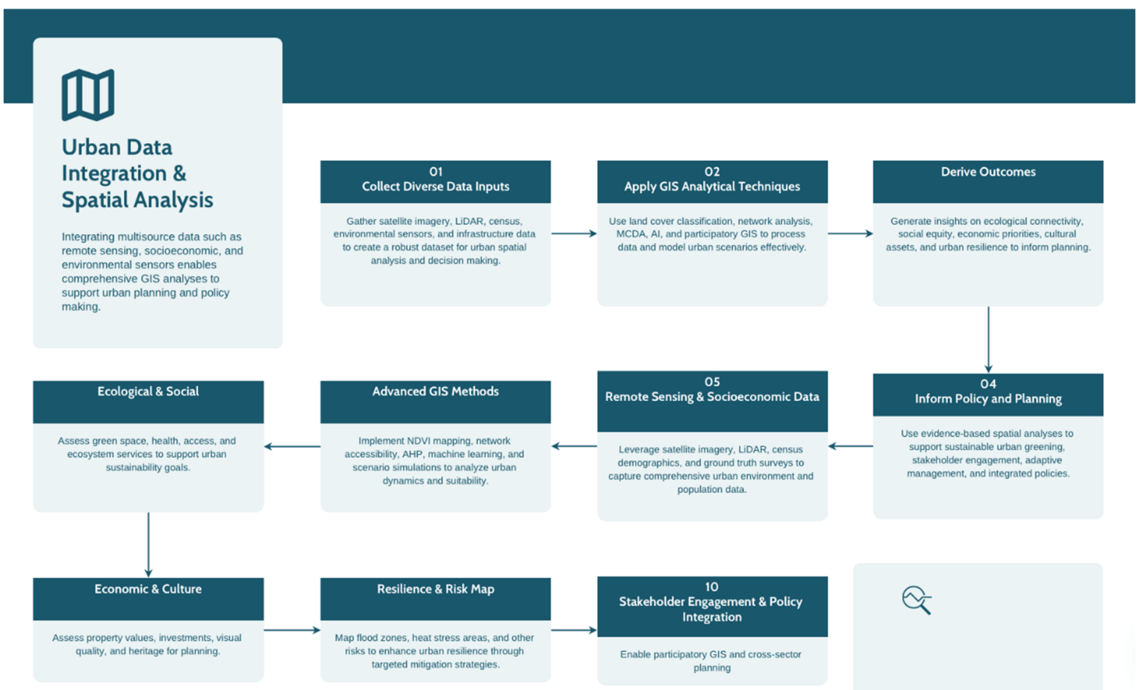
that display accessibility indicators, ecosystem service locations, and expected scenario outcomes improve stakeholder participation and participatory planning.

The emergence of real-time sensor networks and open-source GIS platforms has enabled high-frequency and dynamic observations of urban natural systems. The combination of air quality sensors, microclimate monitors, and mobile device geolocation generates continuous, high-resolution data on the state and efficacy of urban green infrastructure.

Cloud-based analytical platforms have made advanced GIS tools more accessible, encouraging cross-cutting partnerships, collaborative research, and creative green infrastructure design (Hailemariam, 2021).

Discussion

GIS-based assessment methods for urban green infrastructure (UGI) can integrate complex ecological, spatial, and socio-economic datasets, providing a strong foundation for urban sustainability planning (Buchavyi et al., 2023; Vîlcea & űoșea, 2020; Xu et al., 2020). In recent years, these assessments have expanded to encompass spatial layout, environmental services, accessibility, visual aesthetics, and social equity (Waheeb et al., 2023; Hoeben & Posch, 2021). Modern applications go beyond traditional assessments, leveraging GIS to produce intuitive reference maps that directly assist decision-making in urban policy and planning (Buchavyi et al., 2023; Xu et al., 2020).



GIS-based UGI research has advanced beyond simple descriptive mapping to include multidimensional investigations that reveal patterns of green space distribution, accessibility problems, and ecological relationships. Analytical methodologies such as multi-criteria decision analysis (MCDA), least cost modeling, and gravity models enable the simultaneous evaluation of topography, land use, humidity, and social factors, assisting in the prioritization and optimal configuration of green infrastructure (Mobarak et al., 2022; Waheeb et al., 2023; Ghasemi et al., 2022). The combination of several data sources, such as high-resolution satellite imaging, NDVI, point-of-interest (POI), and demographic data, provides a scientific foundation for equitable and efficient green space management (Kim et al., 2021; Pouya and Aghlmand, 2022).

Methodological innovation may be seen in the rising integration of remote sensing (RS) and artificial intelligence (AI), which has improved the precision, scalability, and objectivity of urban green infrastructure (UGI) evaluations. AI-driven image categorization and indication weighting

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reduce human mistake and enable nuanced evaluations, particularly in urban environments with spatial diversity (Bai et al., 2022). Recent research combines visual and aesthetic evaluations with stakeholder-driven techniques, demonstrating a shift toward comprehensive assessment frameworks that consider both objective conditions and subjective preferences (Osseni et al., 2023; Zhang et al., 2024).

The reviewed literature supports and builds on core urban theories, such as urban metabolism and socio-ecological systems, by using spatial analysis to these frameworks (Huang et al., 2023; Ghasemi et al., 2022). GIS spatial analytical functions provide light on the relationships between the distribution of green spaces and social equality, reflecting the "right to the city" notion and providing empirical tools for achieving spatial justice (Ghasemi et al., 2022; Waheeb et al., 2023). A comparison with previous studies demonstrates a significant shift toward interdisciplinarity, as approaches from ecology, computer science, urban planning, and sociology are used to address the complexities of sustainable urban development (Xu et al., 2020; Bai et al., 2022).

This research also differentiates from past evaluations, which focused mostly on ecological indicators, by including social, economic, and aesthetic factors into assessment methodologies. The result is a more nuanced and complete understanding of UGI that is consistent with current discussions about the integration of ecosystem services, human well-being, and environmental justice into urban studies (Hoeben & Posch, 2021; Rachid et al., 2024).

The examined studies' methodological strengths include the meticulous integration of multi-source geographical data, innovative analytical frameworks, and validation processes that combine fieldwork, expert evaluation, and participatory methods (Mohammed & Hammo, 2023; Zhang et al., 2024). The use of MCDA and sophisticated categorization approaches reduces subjectivity and allows for comprehensive assessments across ecological, social, and economic dimensions (Hailemariam, 2021; Ghasemi et al., 2022).

However, numerous constraints remain. Geographical bias is evident, with most case studies focusing on Asia, particularly China, and low representation from the Americas and Oceania, limiting the findings' generalizability (Mobarak et al., 2022; Hailemariam, 2021). Temporal focus, limited to papers published between 2020 and 2024, may miss important advances in GIS-based UGI assessment. Methodological heterogeneity prohibits meta-analysis and cross-case synthesis, while differences in data quality and availability, particularly for high-resolution satellite imagery, can introduce bias (Bai et al., 2022; Buchavyi et al., 2023).

The comprehensive findings offer useful insights on urban planning and governance. GIS-based evaluation encourages evidence-based site selection for green space extension, supports targeted interventions in areas of ecological or socioeconomic risk, and serves as a platform for ongoing monitoring and adaptive management (Kim et al., 2021; Yang, 2024). Policymakers can use these technologies to promote spatial fairness, reduce urban heat islands, and improve ecological services, while participatory GIS platforms (PPGIS) make it easier to incorporate community perspectives and preferences into planning procedures (Waheeb et al., 2023).

Institutional and policy support, particularly public investment and regulatory frameworks that mandate the integration of green infrastructure, are critical for incorporating UGI into urban development (Waheeb et al., 2023; Ghasemi et al., 2022). Furthermore, policies that encourage public participation and stakeholder collaboration strengthen the legitimacy and effectiveness of UGI planning (Osseni et al., 2023).

Significant research gaps include the need for more geographical variety in case studies, particularly those from impoverished areas, as well as the standardization of evaluation frameworks to promote cross-comparison and meta-analysis. Future research should prioritize the use of real-time sensor data, hyperspectral imaging, and sophisticated AI-driven analytics to detect dynamic changes in UGI quality and function (Xu et al., 2020; Bai et al., 2022). Collaboration across disciplines, particularly among spatial scientists, ecologists, sociologists, and policy analysts, will be critical to the growth of the field.

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There are opportunities to investigate the long-term consequences of UGI interventions on urban resilience, public health, and social cohesion, as well as the efficacy of participatory methodologies in different cultural and governance contexts (Zhang et al., 2024; Osseni et al., 2023).

The current synthesis is constrained by language and database limitations, which may exclude relevant non-English or gray literature. The reliance on peer-reviewed research from well-known databases ensures quality but may overlook innovative, practical findings. The variety in study design, data quality, and reporting standards increases the likelihood of bias when examining patterns and drawing conclusions.

The GIS-based evaluation of urban green infrastructure is a breakthrough tool in urban studies, allowing for comprehensive, multidimensional, and interactive assessments that incorporate ecological, social, and policy considerations. Methodological advances, notably the use of artificial intelligence, remote sensing, and multi-criteria analysis, have strengthened the empirical foundation for equitable and sustainable urban development. Addressing existing gaps in geographical coverage, standardization, and interdisciplinary integration will increase the importance and influence of GIS-based UGI research. These advances have significant implications for influencing policy, increasing urban resilience, and accomplishing the broader goals of sustainable and equitable cities.

Conclusions

Geographic Information Systems (GIS) have made rapid progress in evaluating urban green infrastructure (UGI), reflecting the growing complexity and multidimensionality of urban sustainability concerns. From 2020 to 2024, research in this sector will gradually combine varied data sources and advanced analytical frameworks, supported by defined methodological rigor and transparent quality criteria (Buchavyi et al., 2023; Mohammed & Hammo, 2023; Mobarak et al.,2022). Systematic literature reviews highlight a rigorous selection procedure, often based on the PRISMA standard, that favors empirical research and the inclusion of diverse urban environments (Mobarak et al., 2022).

Modern GIS-based UGI evaluation uses a wide range of datasets, including governmental, commercial, academic, and open-source sources, as well as remote sensing imagery and field survey data (Ghasemi et al., 2022). Analytical procedures commonly employ spatial statistics, network analyses, multi-criteria decision analysis (MCDA), and machine learning techniques, with a growing emphasis on artificial intelligence for data integration and interpretation (Kim et al., 2021; Xu et al., 2020). These techniques examine UGI across various aspects, including accessibility, ecosystem services, resilience, social benefits, and aesthetics, displaying a full awareness of the urban landscape (Vîlcea & Șoșea, 2020; Zhang et al., 2024).

The study demonstrates a substantial shift from ecological evaluations to more holistic assessments that consider social equality, aesthetic quality, and community preferences (Hailemariam, 2021). Spatial assessments now frequently combine quantitative indicators like the normalized difference vegetation index (NDVI) and proximity to facilities with subjective data from resident surveys to address both environmental and social elements of urban green infrastructure (Ghasemi et al., 2022). Site selection and policy interventions are increasingly facilitated by decision-support techniques such as suitability mapping and the analytic hierarchy process (AHP), which incorporate a variety of weighted criteria (Mobarak et al., 2022).

Technological improvements have changed GIS from a simple mapping tool to an essential decision-support platform capable of visualizing and optimizing urban green infrastructure of varied sizes. Multi-source data fusion and multidisciplinary approaches are now the foundations of advanced evaluations, ensuring the simultaneous examination of ecological, social, economic, and aesthetic issues (Mironova, 2021; Bai et al., 2022). Fieldwork is essential for providing ground truth confirmation and documenting contextual aspects that distant sensing cannot detect.

A study of 20 recent studies found that high-quality GIS-based UGI research often follows strict inclusion, exclusion, and quality evaluation processes, ensuring reproducibility and relevance

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(Mobarak et al., 2022). The findings show that GIS-based UGI evaluation is becoming more participatory and adaptable to changing urban needs, allowing for the fair and robust growth of green infrastructure. As the subject advances, methodological breakthroughs and the incorporation of novel technologies are expected to strengthen the empirical basis for UGI planning, putting GIS at the center of urban sustainability research (Mironova, 2021; Bai et al., 2022).

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