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The Impact of Green Infrastructure on the Development of a Smart Sustainable City (Case Study: The Metropolis of Karaj)

Atta Ghaffari Gilandeh[1*],Mansour Rahmati[2],Mohamad Mahdi Mahabadi pour[3],Yasser Afshoun[4]

[1.] Professor, Department of Geography and Urban Planning, Faculty of Social Sciences, University of Mohaghegh Ardabili, Ardabil, Iran.
[2.] Associate Professor, Department of Geography and Urban and Rural Planning, Faculty of Social Sciences, University of Mohaghegh Ardabili, Ardabil, Iran.
[3.] PhD Student, Department of Geography and Urban Planning, Faculty of Social Sciences, University of Mohaghegh Ardabili, Ardabil, Iran.
[4.] PhD Student, Department of Geography and Urban Planning, Faculty of Social Sciences, University of Mohaghegh Ardabili, Ardabil, Iran

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Abstract

Background and Objective: With the rapid pace of urbanization and its associated environmental challenges, novel approaches such as the smart sustainable city and green infrastructure have become essential. However, the gap between theory and practice, particularly regarding the prioritization of interventions, persists. This study was conducted with the objective of analyzing the impact of green infrastructure on the realization of a smart sustainable city and providing a data-driven framework for spatial prioritization in the metropolis of Karaj.

Methodology: This is an applied study employing a descriptive-analytical method. Initially, 24 key variables were identified and distributed to 30 experts via a questionnaire. Subsequently, using a hybrid approach, the Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) technique was utilized to identify key drivers, and the Combined Compromise Solution (CoCoSo) method was employed to rank the readiness of the 11 urban districts of Karaj.

Results and Findings: The results indicated that seven drivers, including "permeable surfaces," "ecological corridors," "investment," and "integrated governance," are the most powerful factors influencing the system. Furthermore, the CoCoSo analysis identified District 5 as the most suitable area for initiating projects. The findings emphasize that a successful transition to a smart sustainable city requires an integrated strategy that simultaneously focuses on physical infrastructure, governance factors, and economic incentives, and that policies must be formulated based on spatial priorities. Ultimately, this study shows that the realization of a smart sustainable city in Karaj is only possible through an integrated strategy that incorporates the key physical, governance, and economic drivers within specific spatial priorities.

Keywords: "Green Infrastructure", "Smart Sustainable City", "Karaj Metropolis", "MICMAC", "CoCoSo".

[*] **Correspong Author Email**: a_ghafarigilandeh@uma.ac.ir

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EXTENDED ABSTRACT

Introduction

With rapid urbanization and growing environmental and social challenges, traditional urban management paradigms have lost their effectiveness. This has led to the emergence of new approaches such as the "smart sustainable city" and "green infrastructure." Green infrastructure, defined as a network of natural and semi-natural spaces, provides vital ecosystem services, such as water management and improved air quality, making it a key tool for achieving sustainability. Conversely, the smart city approach utilizes digital technologies for optimal resource management. The integration of these two approaches smartening green infrastructure through the use of sensors and data can significantly enhance their efficiency, transforming them into active and effective elements within the urban network. Despite the clarity of the theoretical foundations, Iranian metropolises like Karaj face serious practical challenges. As a major population hub, Karaj is confronted with a severe shortage and highly inequitable distribution of green space; its per capita green space is far below established standards, and its distribution across different districts is highly unequal. This situation, combined with scattered and reactive management approaches, has significantly reduced the city's resilience to crises such as floods and air pollution, while overlooking the potential for smart solutions. Therefore, this research addresses this gap by analyzing the impact of green infrastructure on achieving a smart sustainable city in Karaj. The primary question is how this potential can be leveraged as a smart driver to solve complex urban problems. To this end, the study, in addition to analyzing overall effectiveness, seeks to identify and prioritize areas that are most ready in terms of infrastructure and social conditions—for the implementation of smart green infrastructure projects.

Methodology

This is an applied, descriptive-analytical study. Data were gathered through documentary, library, and field research. The field study involved a validated survey of 30 experts in urban planning and the environment. For analysis, a hybrid approach was used: the CoCoSo method for prioritization and the MICMAC technique to identify key influential variables. GIS software was also utilized for spatial analysis and mapping, enabling a comprehensive assessment of the topic.

Results and Findings

This research analyzed the impact of green infrastructure on achieving a smart sustainable city in Karaj. The findings, based on a hybrid MICMAC and CoCoSo approach, indicate that success depends on a simultaneous combination of physical infrastructure, governance factors, and economic drivers, with smart technologies playing a facilitative role. By identifying key drivers (such as investment and integrated governance), the study transforms abstract contextual factors into actionable policy variables, demonstrating that a sole focus on technology without these foundational drivers will lead to failure. While previous research has emphasized the general importance of green infrastructure, the main innovation of this study is providing a practical, data-driven framework to answer the "how and where" questions. This work bridges the gap between theory and local operational action, offering city managers a scientific roadmap for prioritizing interventions.

Conclusion

This research demonstrated that the transition towards a smart sustainable city is not a uniform, universal process, but rather a strategic coordination of key drivers and spatial priorities. The analysis of the findings revealed that the driving engine of urban transformation is powered not by technology alone, but through the synergistic interaction among three primary domains: fundamental physical infrastructure, enabling governance mechanisms, and socio-economic drivers. This profound understanding shifts the paradigm from a mere focus on technological solutions towards creating an integrated, multidimensional platform, and emphasizes that success in this domain relies primarily on intelligent, evidence-based decision-making. Among the primary innovations of this research is the provision of an analytical framework for urban management that enables moving beyond broad, generalized policies. The results of the district ranking in the Karaj metropolis revealed the undeniable reality that cities are composed of heterogeneous districts, each possessing different levels of readiness and capacities. The hybrid framework employed allows for investments and interventions to be directed in a targeted and focused manner towards areas with the highest potential for return, thereby preventing the waste of resources in unsuitable areas. This approach effectively bridges the gap between macro-level urban theories and local-level operational actions. Ultimately, this research emphasizes a fundamental principle of contemporary urban governance: the future of cities is not shaped through scattered and reactive interventions, but is the product of integrated, data-driven, and strategic planning. The model presented in this study, by transcending the Karaj case study, may offer a replicable model for other metropolises, enabling them to, with greater confidence, map out and navigate their path towards sustainability and smartness.

Declarations

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Authors' Contribution
Authors contributed equally to the conceptualization and writing of the article. All of the authors approved the content of the manuscript and agreed on all aspects of the work declaration of competing interest none.

Conflict of Interest
The authors declare no conflict of interest.

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