

GREEN INFRASTRUCTURE MULTIFUNCTIONAL NETWORKS AND WATER-FOCUSED APPROACH: A LITERATURE ANALYSIS

INFRAESTRUTURA VERDE REDES MULTIFUNCIONAIS E ENFOQUE HÍDRICO: UMA ANÁLISE DE LITERATURA

INFRAESTRUTURA VERDE REDES MULTIFUNCIONALES Y ENFOQUE HÍDRICO: UN ANÁLISIS DE LA LITERATURA

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ABSTRACT

Between 2013 and 2023, Green Infrastructure (GI) emerged as a key component in promoting sustainable urban initiatives. Its rise was marked by an interdisciplinary approach that fostered the integration of diverse fields, establishing it as a foundational element in sustainable urban projects. GI aimed at creating resilient and sustainable cities by enhancing biodiversity, improving environmental quality, and contributing to climate change mitigation. This study aimed to analyze trends in GI, indicating that its scope extended beyond water-related issues to encompass multifunctional green networks. The research was conducted in two phases. Initially, a survey was carried out using the keyword "green infrastructure." Subsequently, two sets of research were outlined, with the first focusing on water-related terms: "Drainage," "Stormwater," "Rain-Garden," while the second focused on multifunctional green networks: "Landscape," "Nature-based solutions," "Urban Forest," "Implantation." The research, across both phases, reviewed 4,395 articles by country, highlighting the diversity and evolution in the definitions and applications of GI, varying by the year of publication. Of the reviewed articles, 1,545 focused on GI and multifunctional green networks, while 2,073 examined water-related issues. The research on GI grew from 2013 to 2023, especially in the USA, China, and Europe.

KEYWORDS

Nature-Based Solutions; Sustainable Cities, Interdisciplinarity; Urban Forest.

RESUMO

No período entre 2013 e 2023, a Infraestrutura Verde (IV) ascendeu como um elemento fundamental no fomento de iniciativas urbanas sustentáveis. Essa ascensão foi notável pela sua abordagem interdisciplinar, que promoveu a integração de campos diversificados, tornando-se um pilar essencial em projetos urbanos sustentáveis. A IV visou cidades resilientes e sustentáveis, promovendo biodiversidade, melhorando a qualidade ambiental e contribuindo para mitigar mudanças climáticas. Este estudo objetivou analisar tendências na IV, mostrando que seu escopo foi além de questões hídricas, abrangendo redes verdes multifuncionais. A pesquisa foi conduzida em duas fases. Na primeira etapa, procedeu-se a um levantamento utilizando a palavra-chave "green infrastructure". Na segunda etapa, dois conjuntos de pesquisa foram delineados, com o primeiro focando em termos ligados a questões hídricas: "Drainage",



“Stormwater”, “Rain-Garden”, enquanto o segundo concentrou-se em redes verdes multifuncionais: “Landscape”, “Nature-based solutions”, “Urban Forest”, “Implantation”. A pesquisa, com suas duas fases, avaliou 4.395 artigos por país, destacando a diversidade e evolução nas definições e aplicações da IV, variando conforme o ano de publicação. Dos artigos revisados, 1.545 focaram em IV e redes verdes multifuncionais, enquanto 2.073 examinaram questões hídricas. A pesquisa sobre IV cresceu de 2013 a 2023, especialmente nos EUA, China e Europa.

PALAVRAS-CHAVE

Soluções Baseadas na Natureza; Cidades Sustentáveis; Interdisciplinaridade; Floresta Urbana.

RESUMEN

Entre 2013 y 2023, la infraestructura verde (IV) emergió como un componente clave en la promoción de iniciativas urbanas sostenibles. Su ascenso estuvo marcado por un enfoque interdisciplinario que fomentó la integración de campos diversos, estableciéndola como un elemento fundamental en proyectos urbanos sostenibles. La IV tuvo como objetivo crear ciudades resilientes y sostenibles mediante la mejora de la biodiversidad, la mejora de la calidad ambiental y la contribución a la mitigación del cambio climático. Este estudio tuvo como objetivo analizar las tendencias en la IV, indicando que su alcance se extendió más allá de los problemas relacionados con el agua para abarcar redes verdes multifuncionales. La investigación se llevó a cabo en dos fases. Inicialmente, se realizó una encuesta utilizando la palabra clave "infraestructura verde". Posteriormente, se delinearon dos conjuntos de investigaciones, con el primero enfocado en términos relacionados con el agua: "drenaje", "aguas pluviales", "jardín de lluvia", mientras que el segundo se centró en redes verdes multifuncionales: "paisaje", "soluciones basadas en la naturaleza", "bosque urbano", "implantación". La investigación, en ambas fases, revisó 4,395 artículos por país, destacando la diversidad y evolución en las definiciones y aplicaciones de la IV, variando por el año de publicación. De los artículos revisados, 1,545 se centraron en la IV y redes verdes multifuncionales, mientras que 2,073 examinaron problemas relacionados con el agua. La investigación sobre la IV creció de 2013 a 2023, especialmente en los EUA, China y Europa.

PALABRAS CLAVE

Soluciones Basadas en la Naturaleza; Ciudades Sostenibles; Interdisciplinariedad; Bosque Urbano.

1. INTRODUCTION

Green Infrastructure (GI) has emerged as an interdisciplinary field of research over the past few decades, spanning areas such as Architecture, Urban Planning, Engineering, Ecology, Economics, Humanities, and Social Sciences. This approach aimed to create resilient and sustainable cities by promoting biodiversity, improving air and water quality, providing recreational spaces, and contributing to climate change mitigation.

Given the growing concern over climate change and sustainable development, the management of stormwater and sustainable urban practices have driven the adoption of concepts such as sustainable drainage and rain gardens, making GI a promising solution to address these challenges.

The fundamental principles of GI permeated various aspects, from the interconnectivity between green areas to the meticulous assessment of the existing infrastructure in the specific context of its implementation. This focus, outlined by Benedict e McMahon (2002), was characterized by a long-term commitment, marked by careful consideration of local dynamics and the need to fully respect the interests and properties of those involved. The scientific approach underlying such concepts emphasized the importance of careful and sustainable implementation of Green Infrastructure, aiming to maximize its environmental and social benefits.

The GI approach proposed the preservation and utilization of environmental services inherent to natural functioning, encompassing various typologies for the creation of multifunctional landscapes that integrated into the conventional urbanization system, as outlined by Schutzer (2014). This focus sought not only to incorporate nature into the urban environment but also to establish more balanced and healthy urban spaces, where the active presence and participation of nature played a fundamental role in the configuration and sustainability of the city's infrastructure.

Achieving the outlined objectives required the participation of professionals from different disciplinary areas in the projects, given the heterogeneous scope of GI, which ranged from recreational spaces, such as parks and green areas, to integrated systems for sustainable water and transport management. The diversity of interpretations and perspectives attributed to GI by these professionals required an inclusive approach, aiming for a holistic understanding of its elements and the maximization of the desired outcomes.

The synergistic integration of diverse specialties not only enriched the design and execution of projects but also promoted a broader and more effective understanding of GI, fostering the effectiveness of the proposed solutions and optimizing their socio-environmental impact.

Research related to the global and multi-scalar vision of GI as multifunctional networks, embedded in urbanism and landscape and reaching urban and territorial planning policies, has seen a significant increase in interest, indicating a greater diversity of fronts for GI as a sustainability tool beyond the water system.

The study of the concepts and applications of GI at an international level required a comprehensive analysis of existing publications in the countries in question, such as Brazil, USA, China, and the United Kingdom. The approach consisted of mapping the current scenario through a systematic review of articles, seeking to understand emerging trends and dominant topics in discussions about GI in these contexts. This article aimed to provide an in-depth view of the scientific and technical perspectives adopted by these countries, facilitating the identification of strategic directions and research gaps in the area of GI on a global scale.

In this context, the present research aimed to present an overview of current publications on GI, comparing terms related to water-related concepts and multifunctional green networks, while highlighting the expansion of the scope of application of GI beyond water issues, also encompassing areas related to multifunctional green networks. This approach aimed to elucidate both the trends and relevant themes in the field of GI as well as demonstrate its interdisciplinary applicability.

2. MATERIAL AND METHODS

Through conducting a bibliographic research of a quantitative nature, this study facilitated the analysis of terminologies associated with Green Infrastructure (GI) on a global scale. Relevant documents were located using the Scopus database due to its breadth, being considered the largest database of abstracts and citations of peer-reviewed literature. (COLODETTI SUELA; ROCHA MORETO; RANDOW DE FREITAS, 2021).

The search on the GI theme was carried out in the following countries which presented the highest numbers of published articles: Brazil, United States, China, Germany, Italy, United Kingdom, Spain, Sweden, Australia, Poland, Netherlands, Canada, Portugal, Austria, France,

Finland, Switzerland, Norway, Belgium, and South Korea.

The aim was to identify the occurrence of the term "Green Infrastructure" and its association with the following keywords: "Landscape OR Nature-based solutions OR Urban Forest OR Implantation OR Drainage OR Stormwater OR Rain-Garden." The data collection was conducted in November 2023, covering the period from 2013 to 2023. This temporal selection was intended to collect the most updated production on the theme, while also obtaining a significant volume of data for analysis.

In the first stage, articles containing the term "Green Infrastructure" were identified. The analysis used the raw results of this term's survey in the period 2013-2023. This initial stage was crucial for establishing a preliminary database, using the results obtained through a comprehensive search for this specific term. This procedure allowed the capture of a broad spectrum of research related to GI and facilitated the subsequent filtering and detailed analysis of the data.

In the second stage, the analysis was divided into two distinct segments, aiming for a more refined categorization of the themes addressed in the identified publications. To this end, two groups of keywords were defined for the search:

- Group 1: Included the combination of "Green Infrastructure" with "Landscape OR Nature-based solutions OR Urban Forest OR Implantation," explicitly excluding any works associated with the terms "Drainage OR Stormwater OR Rain-Garden." This group aimed to isolate studies focusing on more comprehensive aspects of GI, such as nature-based solutions, urban forests, and their implementation, avoiding the predominance of themes related to stormwater management.
- Group 2: Focused on "Green Infrastructure" associated with "drainage OR stormwater OR rain-garden," directing the analysis towards studies addressing GI primarily from the perspective of urban stormwater management and control.

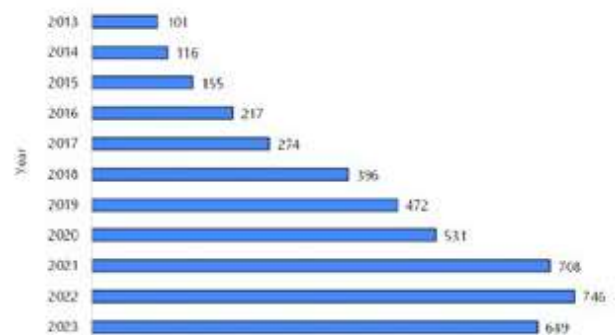
The distinction and analysis of these two groups aimed to identify the predominant discussion axes within the GI field, starting from the initial hypothesis that the theme related to stormwater management could be a significant focus in research. However, by segmenting the studies in this way, the study also sought to reveal other dimensions and approaches to GI that may be present in the global scientific production, contributing to a more

holistic and diversified understanding of the theme. This method allowed a quantitative analysis of the articles and a qualitative assessment of the trends, themes, and predominant approaches in the study of GI over the last decade.

3. RESULTS AND DISCUSSION

3.1 Overall volume of articles

In the initial data mining phase, a total of 4,395 articles were identified that included the term 'green infrastructure'. Of these, 1,545 articles met the inclusion criteria "Landscape OR Nature-based solutions OR Urban Forest OR Implantation", while 2,073 articles were associated with the terms "Green Infrastructure and drainage OR stormwater OR rain-garden".

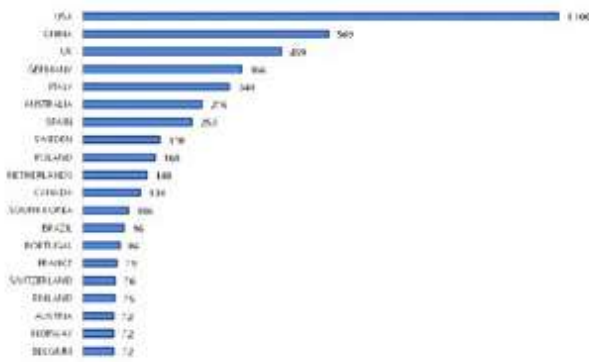


Graph 01: Publications in the period from 2013-2023 with the term green infrastructure.

Source: Scopus, adapted by the authors (2023)

Graph 1 showed a significant increase in the volume of articles over the research period, from 101 in 2013 to 689 in 2023 (January to November). It was also noted that, from 2016 to 2021, there was an acceleration in this volume, demonstrating an average annual growth rate of 26.26%, indicating the growing interest in the topic as a subject of research. In 2013, the volume of articles constituted 2.29% of the total value, and in 2023, this figure rose to 15.64%.

Comparing terms related to Multifunctional Green Networks and Drainage found in the green infrastructure articles showed that the selected search terms led to diverse research focuses, with varying emphases on the topics discussed.



Graph 02: Countries with most publications in the period from 2013 – 2023 using the term green infrastructure

Source: Scopus, adapted by the authors (2023)

It was noted that, except for the United States, which occupied the first position, the countries with the highest scientific production in green infrastructure (GI) were located in Europe, indicating that in recent years European countries have advanced in research and implementation of green infrastructure strategies, probably as a consequence of the publication of the European Parliament Resolution, on September 17, 2020, which emphasized GI as a tool to achieve more green city planning.

The deliberate exclusion of terms associated with drainage and stormwater management was intended to focus specifically on elements that exclude the approach to GI merely related to stormwater management. This decision suggests a particular interest in addressing aspects of green infrastructure that do not directly relate to water issues.

By avoiding specific water-related terms, the focus seems to be directed at features and functionalities of green infrastructure that transcend conventional stormwater management, indicating a broader interest in other dimensions and benefits of this type of urban infrastructure.

When the distribution by countries was analyzed (Graph 2), the United States led in number with a total of 1,100 articles, which amounted to 24.97% of the total publications for the period. Following, China contributed 569 articles, representing 12.91% of the publications and about half of the United States' output. Brazil occupied the 14th position, having published 96 articles, which accounted for 2.17% of the total publications in this period.

The year 2022 stood out for the highest number of publications, totaling 746 articles indexed in journals; this increase could be associated with the holding of the United Nations Climate Change Conference (COP 26), held on November 12, 2021, in Glasgow, Scotland.

3.2 Publications on green infrastructure related to multifunctional green networks

In stage 2, group 1, a comprehensive research was conducted on articles related to the field of landscaping and multifunctional green networks as demonstrated by the studies of Herzog (2016); Lovell; Taylor (2013); Scott et al. (2016); Siehr; Sun; Aranda Nacamendi (2022); Verdú-Vázquez et al. (2021). Our goal was to identify materials that specifically addressed the integration of green infrastructures, highlighting the importance of GI in this context.

The results regarding the volume of scientific productions revealed prominence for the United States, China, Germany, Italy, and the United Kingdom. Brazil appeared in the 14th position (Chart 3).



Graph 03: The top 10 countries with the most publications using terms related to green infrastructure and multifunctional green networks.

Source: Scopus, adapted by the authors (2023)

The publications presented a diversity of themes, ranging from the development of strategies for the creation of open spaces to the promotion of approaches based on natural elements in the urban context.

The surveyed works provided a panoramic view of the central themes addressed in the literature related to multifunctional green networks. The generated word cloud offered a refined view of the predominant topics in the analyzed articles (Figure 1). This visual representation emphasized the concepts and specific terminologies that were central in the scope of green infrastructure and multifunctional green networks. Terms such as "biodiversity," "ecology," and "sustainability" emerged as focal points, reflecting the relevance of these themes in contemporary research. The occurrence of words like "management" and "planning" suggested an approach aimed at the effective application of green infrastructure concepts in urban environments. Furthermore,

the presence of terms related to "ecosystems" and "urbanization" highlighted the growing interest in the interaction between natural and built spaces. This visual synthesis served as a useful tool for identifying the main areas of interest and emerging trends in research on multifunctional green networks and their role in cities.



Figure 1: Word cloud of green infrastructure articles related to multifunctional green networks
Source: Authors (2023)

It has been observed a steady increase in publications over the years in the United States, reaching a peak in 2021. Green Infrastructure (GI) was considered a holistic approach to incorporating natural elements and ecological systems into urban spaces, regardless of scale, to provide environmental, social, and economic benefits (VAN DER JAGT et al., 2019). GI aimed to improve the quality of life in cities, making them more sustainable and resilient (PARKER, 2023).

China showed significant growth in publications, with a notable increase starting in 2019. This could reflect the country's increasing commitment to sustainable practices and Nature-Based Solutions. This fact was related to the challenge faced by China, resulting from its rapid urban growth, climate change, air and water pollution, loss of biodiversity, and environmental degradation (LI et al., 2021).

GI in Chinese production referred to the use of natural elements, such as urban parks, green areas, bodies of water, green belts, green roofs, and squares with vegetation, as a strategy to deal with various urban problems, such as air quality, urban heat islands, sustainable water management, and promoting biodiversity in urban areas (YAO et al., 2022).

GI played a key role in transforming Chinese cities into more sustainable, resilient, and pleasant environments for their inhabitants, in addition to contributing to the preservation of the environment in a highly urbanized, industrialized, and rapidly growing country (LI et al., 2018).

The steady volume of publications over the years in countries like Germany, Italy, and the United Kingdom indicated that these countries were interested in and regularly involved in the GI theme, possibly incorporating it into territorial urban planning and management of urban

spaces. This could be observed in the conceptualization of GI as an essential element of urban and regional planning through goals and implementation initiatives. Some developments of the concept into planning actions were highlighted, as mentioned in the scientific production in these countries.

- **Improving Quality of Life: Green Infrastructure (GI)** was perceived as a means to enhance the quality of life for citizens. This involved access to green spaces for recreation, leisure, and outdoor activities, in addition to promoting mental and physical health (STURIALE; SCUDERI, 2019).
- **Environmental Resilience:** GI was seen as an element that played a vital role in mitigating the impacts of climate change, such as heatwaves. It contributed to reducing air pollution and preserving local biodiversity (ALLAM; JONES; THONDOO, 2020).
- **Biodiversity and Conservation:** The promotion of biodiversity was clearly a fundamental component of GI in these countries. Urban green spaces and natural areas were carefully planned and managed to support the integrity of local flora and fauna.
- **Connectivity and Ecological Corridors:** The creation of ecological corridors that connected green areas was essential to facilitate the movement of species and their adaptation to changing environmental conditions (JONES et al., 2022).
- **Community Engagement:** Community participation was encouraged in both the development and maintenance of GI. This could include the creation of community gardens, tree planting programs, and other activities (ANGUELOVSKI et al., 2022).
- **Policies and Incentives:** In the countries researched, there was the implementation of policies and incentives to promote GI, such as the promotion of green roofs, green walls, and urban green spaces (BURSZTA-ADAMIAK; FIAŁKIEWICZ, 2019).

- Sustainable Urban Planning: The integration of GI into urban planning was fundamental to building more sustainable and pleasant cities (MELL; CLEMENT, 2020). This included the creation of green zones in cities, the promotion of public transport, and the planning of accessible public spaces.

In this context, these European countries and China explored green infrastructure as interconnected multifunctional networks, aiming to enhance air quality, plan resilient spaces to preserve biodiversity through the implementation of ecological corridors. Moreover, they sought to actively involve the community in executing these initiatives, with the goal of promoting more sustainable urban planning.

Brazil, ranked 14th, showed a lower volume of productions compared to the countries mentioned previously. Nonetheless, a notable increase was observed from 2019, gaining importance as concerns over sustainable urban development and the mitigation of environmental impacts became more pressing. Green Infrastructure (GI), often referred to as "urban GI" or "green urbanism," is an approach that, here, as observed in the countries already mentioned, is perceived as an element promoting the integration of natural elements and ecological systems in urban areas.

Ecological systems are understood as natural systems that encompass biotic and abiotic components interacting in a specific environment. As mentioned by Marques (2020), it aimed not only to improve the quality of life in cities but also to address extreme events resulting from climate change, mitigating damages and adapting the city when possible to avoid harm.

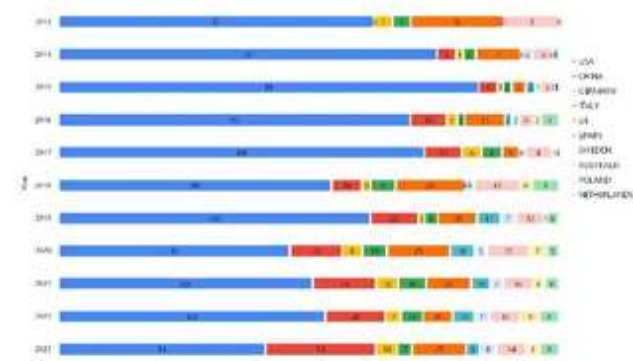
GI in Brazil encompassed a range of strategies and practices aimed at making cities resilient. The adoption of GI played a fundamental role in promoting sustainable urban development and improving the quality of life for urban inhabitants.

The deliberate exclusion of terms associated with stormwater drainage and management was intended to specifically focus on elements not directly linked to stormwater management. This decision suggests a particular interest in addressing aspects of green infrastructure that do not directly relate to water issues.

By avoiding specific water-related terms, the focus seemed to be directed at characteristics and functionalities of green infrastructure that transcend conventional stormwater management, indicating a broader interest in other dimensions and benefits of this type of urban infrastructure.

3.3 Indexed articles on green infrastructure related to water issues

A search was conducted in articles specialized in the field of water-related aspects of green infrastructure, aiming to identify research that focused particularly on the integration of green infrastructures within the water domain, with special emphasis on stormwater management as highlighted by Diep; Dodman; Parikh (2019; Lovell; Taylor (2013); Nguyen et al. (2019); Radinja; Atanasova; Lamovšek (2021). This analysis covered scientific works that explored the intersections between green infrastructure and issues related to the sustainable management of stormwater in urban environments (Figure 4).



Graph 1: The top 10 countries with the most publications on green infrastructure terms related to water issues.

Source: Scopus, adapted by the authors.

A word cloud, generated from the surveyed works on green infrastructure related to water issues, provided a panoramic view of the predominant themes. This graphical representation highlighted frequently used terms, indicating research focuses and areas of interest (Figure 2). Words like "ecosystem," "management," "sustainability," and "water" were prominent, reflecting the emphasis on the intersection between ecology and water resources. The frequency of terms "urban" and "development" suggested a concentration on challenges and solutions in urban contexts. Terms such as "modeling" and "analysis" indicated the methodologies applied, while "policies" and "strategies" pointed to planning and implementation approaches. This keyword analysis offered a comprehensive understanding of current trends, research directions, and core concerns in the interaction between green infrastructure and water resource management.



Figure 2: Word cloud from articles on green infrastructure related to water issues.

Source: Authors (2023).

As demonstrated in Graph 4, the United States led the research scene on Green Infrastructure (GI) related to water issues, with an increasing trend over the years. Emphasis was placed on integrating nature-based solutions, such as bioretention and permeable pavements, into the effective management of urban stormwater (STADDON et al., 2018).

China showed significant growth in article production in the context of drainage with GI. The strategies adopted in Chinese cities to cope with rapid urban development and the challenges associated with stormwater management through the implementation of green roofs and permeable pavements stood out as an integral part of GI (CHESHMEHZANGI, 2022).

In European countries, research showed variations over the years. The policies and practices adopted in Europe to promote green infrastructure as a viable solution for stormwater management were highlighted by Mell and Clement (2020).

In these countries, a detailed approach to green infrastructure was adopted to tackle water challenges, focusing on improving urban drainage and planning urban spaces that are functional and resilient. This involved the implementation of innovative solutions to promote sustainable practices in stormwater management, highlighting the importance of urban green spaces in effectively dealing with water issues (LIU; JENSEN, 2018).

The bibliometric analysis revealed an upward trend of interest in GI towards drainage solutions, reflecting a pressing global need to adopt sustainable approaches in the management of urban stormwater. The specialized literature demonstrated that various countries offered unique perspectives to address both local and global challenges associated with stormwater management.

These studies emphasized the importance of incorporating sustainable practices in stormwater management as an integral component of sustainable urban development (MINKS, 2013). The sustainable approach not only addressed environmental concerns but

also contributed to the enhancement of urban resilience in the face of extreme weather events (HANNES, 2019).

A deeper understanding of these practices, coming from different parts of the world, provided a solid foundation for formulating adaptable and contextually relevant strategies at the local level (CANTON, 2013). Therefore, by incorporating lessons learned from successful initiatives in different contexts, it was possible to develop and implement innovative and effective solutions for sustainable stormwater management in urban areas.

This holistic approach not only met the immediate needs of urban communities but also contributed to building more resilient and sustainable cities in the long term.

4. CONCLUSION

This study explored the increasingly broad conceptual scope and trends of the subject, showing that green infrastructure (GI) has transcended water-related issues. The analysis of articles highlighted the diversity of definitions and their applications, reflecting its interdisciplinary nature and geographical variation.

There was a significant increase in the publication of articles on GI from 2013 to 2023, with emphasis on the United States, China, and European countries. This trend underscored the global recognition of the subject as a tool for the development of resilient and sustainable cities. The research revealed two main lines of focus: one oriented towards general aspects of GI, including landscaping and nature-based solutions, and another focused on water issues, both with a growing trend of publications.

In the USA and China, studies emphasized the integration of natural solutions in urban settings, aiming to improve quality of life and environmental resilience. In Europe, GI was approached in urban policies and practices, standing out in stormwater management and in the construction of sustainable cities.

It was concluded that GI is an expanding field, crucial for sustainable urban planning. With its multifunctional and interdisciplinary approach, it offered solutions to urban challenges such as climate change, environmental quality, and biodiversity. The results reinforced the importance of continuing to explore and implement GI in different contexts, promoting healthier, more resilient, and sustainable cities.

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