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Review

The Role of Green Infrastructure in Providing Urban Ecosystem Services: Insights from a Bibliometric Perspective

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Abstract: Urban ecosystems, and the services they provide, are a key focus of the United Nations 2030 Agenda for Sustainable Development, specifically SDG 11, which emphasizes making cities inclusive, safe, resilient, and sustainable. Green infrastructure (GI) is crucial in enhancing citizens' quality of life and achieving this goal and it can be defined as a strategically planned network of natural and semi-natural areas designed to deliver a range of ecosystem services (ESs). These infrastructures improve ecosystem functioning, protect biodiversity, promote health, support sustainable land and water management, and boost the local green economy. This paper explores the scientific literature on GI and their ESs in cities using bibliometric science. By combining the keywords "Green Infrastructures", "Ecosystem Services", and "Cities" with VOSviewer software (1.6.20 version), we analyzed trends over time. Results show growing attention to these topics, emphasizing human well-being, urban resilience, and sustainability. The study also highlights that focusing exclusively on either "Green Infrastructure in Cities" or "Ecosystem Services in Cities" leads to fragmented insights. A more integrated examination of these three domains offers a holistic view and underscores the importance of considering ecosystem disservices. The study further identifies key research directions, including the need for a comprehensive evaluation of diverse GI types, especially those that are under-researched, such as green roofs, sports areas, and wetlands, and the underexplored role of cultural ecosystem services. Additionally, future research should consider both the benefits and disservices of GI to support better urban planning decisions. Finally, integrating biophysical, social, and economic values of ESs is critical for providing more holistic insights and enhancing sustainable urban development. The novelty of this paper lies in its integrated, holistic approach to examining GI and ESs in urban areas, with a focus on ecosystem disservices, insufficient attention to specific GI types, and the role of cultural ecosystem services—each contributing to the creation of more resilient and sustainable cities.

Keywords: green infrastructure; cities; urban ecosystems; ecosystem services; urbanization; SDG 11; bibliometric network analysis; VOSviewer

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1. Introduction

Urban areas are regarded as the core for innovation, employment, and wealth generation [1,2]. However, the rapid rise in urbanization has led to numerous issues that make cities diverge from delivering sustainable living spaces [3]. For example, the challenge of supplying needed goods and services that support the urban metabolism equitably is exacerbated by the rapid growth as well as environmental stresses such as extreme heat or flooding due to climate change [4–6]. For instance, ensuring a stable food supply, providing clean drinking water, managing waste, maintaining energy supply, facilitating public transportation, and delivering healthcare services are all critical components of urban infrastructure that are increasingly strained under these conditions [7–11]. From a land-use perspective, growing cities have a high impact in terms of area converted from previous uses, which were more likely to provide functioning ecosystem services (ESs) [12–14]. As stated in the Millennium Ecosystem Assessment, ESs "are the multiple benefits that people obtain from ecosystems", crucial to ensure human well-being (WB) [15]. Nowadays, urban land cover is still a relatively small fraction of the total Earth surface (3%), but future forecasts expect that urban areas will keep growing, with more than one-half of the world's population moving to urban areas by 2050 [16–18]. Moreover, urban land is often located on highly productive areas such as coastal and riverine, or quality soils. The delivery of ESs from these productive ecosystems led humans to originally settle in those areas [19].

Recognizing the need to deal with urbanization concerns, a global awareness aiming at sustainable management of urban areas has arisen, as witnessed by the actions proposed in the 2030 Agenda for Sustainable Development, the World Forum on Urban Forests, and the UN New Urban Agenda [14,15].

Particularly, the United Nations General Assembly in 2015 considered cities as a priority target, deciding to adopt "Sustainable cities and communities" as a distinct goal (SDG 11) under the 2030 Agenda for Sustainable Development [20–23]. The UN 2030 Agenda and related Sustainable Development Goals (SDGs) represent the global framework for tackling the planet's major challenges at a local and global level, considering in an integrated way the three dimensions of sustainable development: environment, society, and economy. In this Agenda, the targets 11.6 "Reduce the environmental impact of cities" and 11.7 "Provide access to safe and inclusive green and public spaces" of the 11th SDG suggest the need to make cities inclusive, safe, and resilient [16,20–23].

Historically, urban planners relied on conventional engineering approaches to address the challenges imposed by urbanization, without considering the cost–benefit ratio and the sustainability of alternative solutions [24]. To address the issues raised by the 2030 Agenda, Nature-Based Solutions (NBS) or Ecological Engineering (EE) are considered long-term approaches to improve the quality of life in cities, dealing with environmental and socio-economic concerns [25,26]. The concept of NBS brings nature and natural processes into urban areas, emphasizing the role that ecological functions can play in providing multiple ESs that are useful to satisfy the needs of an urban population [27,28]. For this reason, sound urban planning approaches based on NBS are needed to create communities that can sustainably flourish [29,30].

One of the most effective NBS for sustainable cities is the creation and maintenance of green infrastructures (GI) [31,32].

GI is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ESs [26,33]. GI refers to those green spaces (or blue if aquatic ecosystems are considered) that are able to generate benefits to the individual and the community, physically, psychologically, emotionally, and socio-economically [34,35]. The examples of GI solutions include green roofs and walls, functional flood plains, barrier beaches riparian woodland, protection forests in mountainous areas and others [26]. Providing several provisioning, regulating, cultural and supporting ESs, such as microclimate regulation, flood control, air quality regulation, noise pollution mitigation and nature-based recreation, GI aims to conserve and manage biodiversity and urban landscapes, reduce community infrastructure costs, promote economic growth, and enhance the quality of human life [36,37].

An alternative definition of GI was presented in ref. [38] (Figure 1) and was defined as a network of interconnected components that sustain natural processes. These components vary in size and shape based on the type and scale of the resource being protected. Conservation levels are determined by the rarity or ecological importance of natural features, while environmental sensitivity dictates the appropriate level of human interaction. Hubs serve as anchors for natural processes and provide origins or destinations for wildlife. Links connect the hubs, enabling the flow of ecological processes. We have schematically presented this in the accompanying figure.

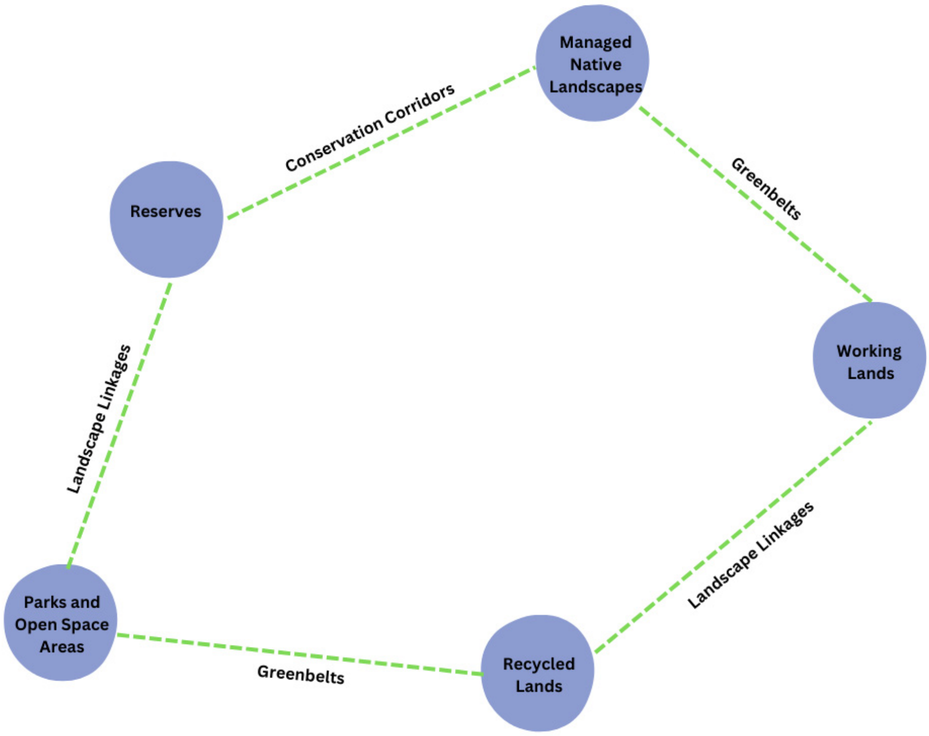

Figure 1. Conceptual green infrastructure system.

Moreover, the concept of green infrastructure already existed in theory under different names such as greenways, garden cities, green belts, and green wedges [39,40]. Frederick Law Olmsted, an apprentice civil engineer, seaman, former nurseryman, and journalist turned American landscape architect, is considered the pioneer of the greenway movement (1880s), which laid the foundation for modern concepts of green infrastructure. Around the same time, in 1899, Ebenezer Howard, an English urban planner, developed the concept of the garden city, which became famous through the "Garden City Movement" [41]. Even though the initial idea of green infrastructure was conceptually linked to Olmsted's work, the first comprehensive and integrative attempts to develop green infrastructure began in Maryland in the 1930s as part of the United States national greenways' initiative [42]. In Charles Little's book, Greenways for America, it is noted that the greenway movement was referred to by different names in various places [43]. For instance, it was called the "greenbelt" in the United Kingdom and the "parkway" in the western United States. However, these terms trace their origins to the word "greenway", combining "green" and "way" to signify natural corridors connecting landscapes [43,44].

The Florida Greenways Commission used the term "green infrastructure" in a formal report in 1994, making it one of the earliest official uses [45]. Benedict and McMahon [46] played a key role in popularizing and formalizing the concept, making it a widely recognized approach in urban planning and environmental conservation. Their work brought together different strands of thinking, such as the greenway movement, ecological networks, and sustainable urban planning, under the umbrella of green infrastructure.

In addition, the term GI is also used to describe strategic approaches to planning green spaces that emphasize network connectivity [47].

The concept of GI highlights the multifunctional roles of urban and peri-urban green spaces, emphasizing the relations between humans and ecosystems [48,49]. In recent years, the ESs and GI concepts have become more integrated into urban planning practices.

According to the European Commission, ecosystem services function as a complement to green infrastructure. ESs and habitat types are examples of GI components in urban areas, allowing cities to adapt and become more resilient to climate change [39].

Research Questions and Goal of the Study

This study aims to answer the following research questions.

Q1: What is the occurrence of research in the areas of green infrastructure and ecosystem services, and how does their integration enhance the understanding of urban sustainability?

Q2: Are there any emerging trends or gaps in the scientific literature about GI, ESs, and cities?

Therefore, the main goal of this study is to explore the above questions to assess the role that GI and ESs have in achieving the 11th SDG and in supporting stakeholders in better urban planning.

2. Materials and Methods

2.1. Bibliographic Research and Data Collection

Documents in this study were collected on 14 January 2024 by search on the Scopus web search engine. The search string used was composed by the following three combinations of keywords: (1) "Green Infrastructures" AND "Cities", (2) "Ecosystem Services" AND "Cities", and (3) "Green Infrastructures" AND "Ecosystem Services" AND "Cities". We retrieved documents published in the timeframe from 1995 to 2023.

2.2. Bibliometric Network Analysis

A bibliometric network analysis with a combination of literature review was conducted in this study to explore the global scientific literature on the topic "Green Infrastructures", "Ecosystem Services", and "Cities" using three different search combinations. The structure of the research is presented in a flowchart (Figure 2).

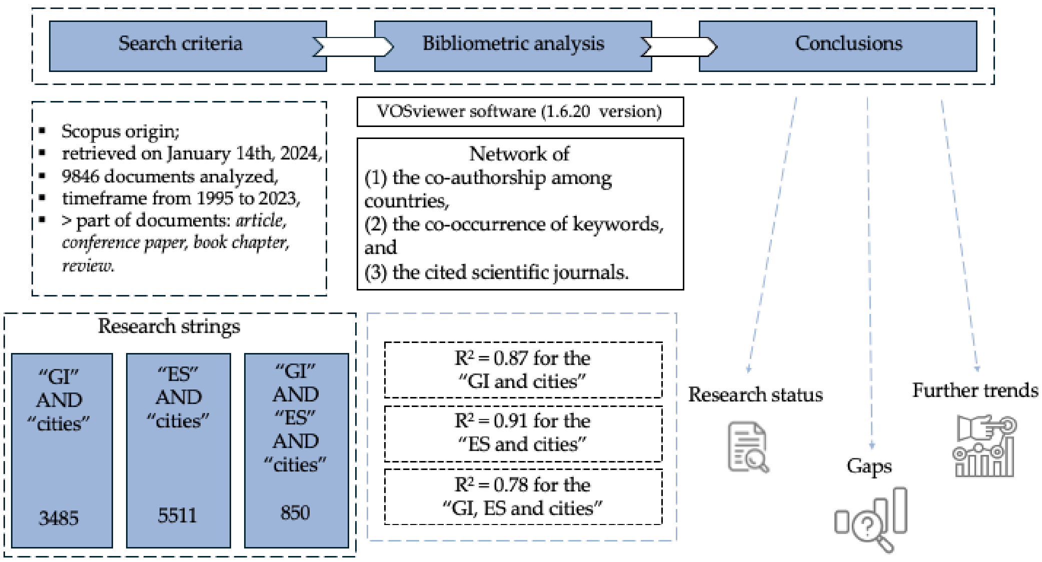

Figure 2. Flowchart of the study.

Bibliometrics uses statistics and quantitative analysis to investigate knowledge structure and the development of research fields [50]. The VOSviewer software (1.6.20 version) was used to generate network maps based on the relationships among countries, journals, authors, and keywords related to the investigated topic. VOSviewer is a software tool allowing for the creation, visualization, and exploration of maps based on bibliometric network data, displaying clusters that support the classification of output results [51]. Table 1 shows the main technical terms used in the software.

Bibliometric network analysis is a quantitative method used to analyze research activities and scientific publications. By examining data from sources like journals, articles, and citations, it identifies patterns, such as how often an article is cited, indicating its impact. This analysis helps track trends in research topics, compare the performance of researchers or institutions, and guide decisions on resource allocation and collaboration patterns. The field of bibliometrics has gained increasing recognition and continues to grow annually [52,53].

Different types of bibliometric networks and maps can be generated by the software. In this study, co-authorship, co-occurrence, and citation analyses were performed to explore the network of (1) the co-authorship among countries, (2) the co-occurrence of keywords, and (3) the cited scientific journals (Table 2). The network maps contain nodes with different sizes, according to the weight attributes (total link strength, number of documents, and number of citation), while the thickness of connections is based on the "link strength". The analysis depends on the chosen resolution, which is a parameter that determines how fine-grained or coarse-grained the clustering of nodes will be in the network. It influences the size and number of clusters or communities that the software identifies within the network. The resolution applied in this study for all the analyses was equal to one. In order to create the maps, thresholds were chosen manually as it enabled us to optimize the visualization for clarity and interpretability. In addition to the bibliometric network analysis, the temporal trend of the number of scientific articles published per year was created (Figure 3).

Table 1. Terminology used by VOSviewer © software. Reprinted with permission from ref. [51] 2009–2023, Nees Jan van Eck and Ludo Waltman.

Term	Description
Items	Objects of interest (e.g., publications, researchers, keywords, authors).
Link	Connection or relation between two items (e.g., co-occurrence of keywords).
Link strength	Attribute of each link, expressed by a positive numerical value. In the case of co-authorship links, the higher the value, the higher the number of publications the two researchers have co-authored.
Network	Set of items connected by their links.
Cluster	Set of items included in a map. One item can belong only to one cluster.
Number of links	The number of links of an item with other items.
Total link strength	The cumulative strength of the links of an item with other items such as between authors, keywords, or documents in a bibliographic dataset. The strength of a link between two items typically represents the frequency of co-occurrence or some other measure of association between them.

Table 2. Different VOSviewer © types of analyses used in this study. Reprinted with permission from ref. [51] 2009–2023, Nees Jan van Eck and Ludo Waltman.

Type of Analyses	Description
Co-authorship	In co-authorship networks, researchers or countries are linked to each other based on the number of publications they have authored jointly.
Co-occurrence	The number of co-occurrences of two keywords is the number of publications in which both keywords occur together in the title, abstract or keyword list.
Citation	In citation networks, two items are linked if at least one cites the other.

3. Results

3.1. Temporal Trend Analysis and Literature Review

The search on the Scopus database using the three research strings generated a total number of 9846 published documents (Table 3 and Figure 3). The results showed the growth and relevance of the investigated topic in the scientific literature over time (Figure 1). All three publication trends from 1995 to 2023, show an exponential growth with the highest value of R^2 = 0.91 for the "ES and cities", R^2 = 0.87 for the "GI and cities", and the smallest value of R^2 = 0.78 for the "GI, ES and cities".

Table 3. Number of documents related to the investigated scientific topic published from 1995 to 2023.

Keywords Search	"GI" AND "Cities"	"ES" AND "Cities"	"GI" AND "ES" AND "Cities"
Total № of documents	3485	5511	850

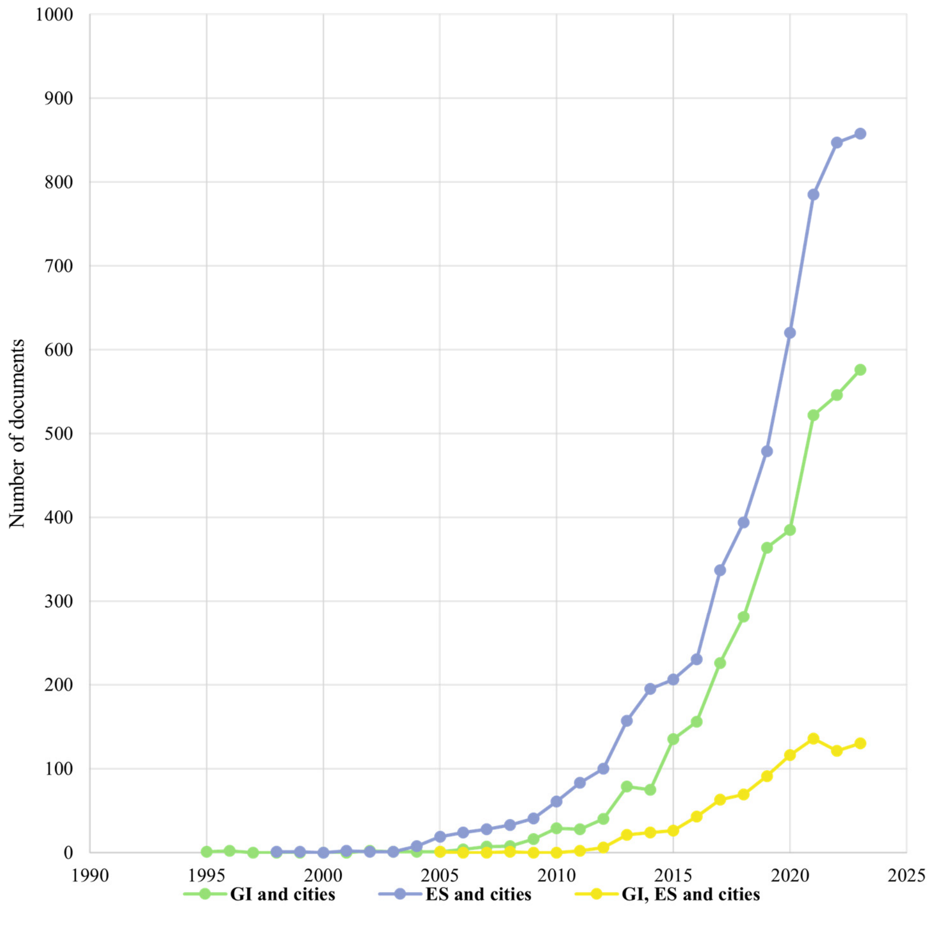

Figure 3. Trend of GI and ES-related publications from 1995 to 2023.

From Figure 3 we can observe the significant interest in this scientific area after 2005 (violet and green lines). The growth of scientific documents can be related to the published international initiative of the Millennium Ecosystem Assessment in 2005, which is a major assessment of the human impact on the environment, called for by the United Nations Secretary-General Kofi Annan. According to the MEA, humans had already degraded 60% of the Earth's ecosystems, jeopardizing their ability to provide services and sustain future generations [15,22]. Notably, The Millennium Ecosystem Assessment reports were among the first to present scientific evidence that, on a global scale, 15 out of 24 assessed ecosystem services, including freshwater, capture fisheries, air and water purification, and regional and local climate regulation, were being degraded or used unsustainably [15,54].

Also, according to Figure 3, the interaction between green infrastructure and ecosystem services is not as strong as they appear to be separately (yellow line). It appears that GI and ESs became more synergistic only after 2010 because GI's definition is younger than ES's. Initially, green infrastructure and ecosystem services were often studied as separate concepts within distinct disciplinary frameworks. However, as research progressed, scholars began to recognize the synergies between them. Green infrastructure, such as parks, green roofs, and urban forests, provides multiple ecosystem services, including air purification, stormwater management, and biodiversity conservation [34]. Additionally, a notable increase in the number of publications has been observed since 2013. Specifically, 2013 marks the year when the European Union adopted the strategy "Green Infrastructure (GI)—Enhancing Europe's Natural Capital", aimed at promoting the widespread adoption and integration of green infrastructure throughout Europe [26]. Understanding these synergies has led researchers to investigate how green infrastructure can be designed and managed to maximize ecosystem service delivery.

To answer RQ1 more comprehensively and enhance the analysis, we conducted a literature review of articles from diverse perspectives.

Our review revealed that many studies focus on GI's role in specific ESs, for example, stormwater management [55,56] or air quality [57,58], but only a few studies [59–61] focus on the role of different types of GI (e.g., urban forests, green roofs) that simultaneously enhance multiple ESs and impacts on well-being. Notably, ref. [59] provides a broader overview, examining how eight types of GI (park, forest, sport area, etc.) influence not only nature systems but also human well-being, highlighting the importance of both ESs supply and demand. In the context of synergy of GI and ESs, a key gap is that stakeholders tend to associate a greater number of ESs with forests, perceiving them as providing more benefits (e.g., regulating services like air purification or recreation) compared to the other seven GI types, such as sports areas or degraded land [59]. Forests received the highest number of ESs assignments, whereas sports areas and degraded lands received far fewer. This suggests that stakeholders prioritize forests, likely due to their visibility and familiarity, but may not fully recognize the multifunctionality of other UGI types.

Additionally, the study demonstrated a linkage between UGI–ES–WB, finding that cultural ESs, compared with provisioning and regulating ESs, have weaker links with WB components (health, security, social relations and basic material for a good life). Cultural ESs have mostly weak or medium relations with WB. This indicates a gap in the UGI–ES relationship, particularly in the lack of studies on GI types (e.g., sports areas) that could enhance cultural ESs and, in turn, promote health and well-being. In ref. [62], various types of green infrastructure, such as urban parks, community gardens, green roofs, and waterfront areas, are identified as valuable for providing cultural ecosystem services (CESs). These spaces should include characteristics like biodiversity, accessibility, aesthetic appeal, and spaces for social interaction, recreation, and mental restoration. Specific features like walkable paths, shaded areas, and proximity to residential zones can help maximize the benefits for different population segments.

Although CESs contribute to human well-being, assessments of them remain less developed than those of service provisioning and regulation. It is also worth keeping in mind that CESs are intangible, so their value is determined more by subjective perceptions of their contribution to well-being than other ES categories. Human–nature interactions are integral to CESs, and this complexity underscores the need for greater attention to CESs in future assessments and monitoring [63]. Study [59] emphasizes the importance of a comprehensive assessment that includes a wider variety of GI types to enhance ESs provision and support all aspects of human well-being. Meanwhile, ref. [64] highlights the significance of balanced attention to both ecosystem services and disservices, for more informed decision making.

As an example of Italian cities, ref. [60] points out a critical gap: the limited integration of green infrastructure into urban planning, particularly in how these spaces are tailored to meet specific local needs. A deeper understanding of how different types of GI (e.g., urban parks, green roofs, and community gardens) deliver specific ecosystem services is essential to optimize their benefits for both nature and society.

In our review of articles on the benefits of GI, we observed that while the positive correlation between green areas and health is well established, the causal relationship between green areas, the ecosystem services they provide, and specific health outcomes remains unclear. This reveals several gaps in the research:

- More studies on diverse types of GI are needed (studies tend to focus disproportionately on forests and parks, often ignoring other types of GI such green roofs, sports areas, greenways or wetlands).
- A more holistic assessment of different ESs is needed (cultural ESs are often neglected [65]).
- Potential ecosystem disservices (e.g., pollen allergy [66,67], invasive species [68], pests [69,70]) should be considered.
- Integration of not only environmental benefits, but also economic [39,71] and social factors [60,71,72].
- More engagement with stakeholders and policymakers is necessary.

Increasing awareness of the importance of various green spaces and their respective benefits can enhance urban planning and the effective use of NBS.

This revision confirms the necessity of investigating GI and ESs together and clearly states that this approach is essential for answering Q1.

3.2. Co-Authorship Analysis of Countries

The co-authorship analyses of countries for the three search combinations were quite similar, and therefore only one network map is shown in Figure 4. The network map reveals patterns of international collaboration. Based on total link strength, the leader countries publishing on the topics of “GI and cities”, “ES and cities”, and “GI, ES and cities” are the United States, the United Kingdom, and Germany (Table 4). The analysis of the map on “GI and cities” showed 140 countries with 64 interactions among them. Articles co-authored by researchers belonging to more than 25 countries were not included in the analysis to avoid a network map with unlinked contributions. For more detailed analysis, we used six for the minimum number of documents of a country and three for the number of citations of a country. In addition, the thickness of the lines in the map indicates the strength of connections between countries over years. For instance, we observed the strong connection of the Unites States with several countries starting from 2019 (such as the United Kingdom and many others), whereas the only recent connection since 2021 is with Iraq.

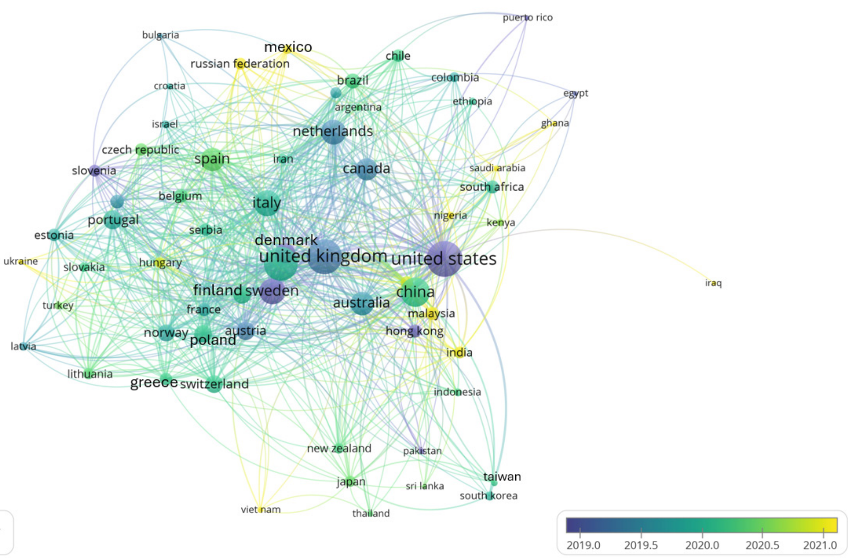

Figure 4. Co-authorship countries network map on “GI and cities” based on total link strength.

Table 4. Main countries based on total link strength generated by VOSviewer.

GI and Cities			ESs and Cities			GI, ESs and Cities		
Countries	**№ of Documents**	**Total Link Strength**	**Countries**	**№ of Documents**	**Total Link Strength**	**Countries**	**№ of Documents**	**Total Link Strength**
USA	840	367	USA	1031	830	Germany	112	119
UK	328	355	Germany	472	613	UK	96	107
Germany	285	327	UK	408	561	USA	174	104
China	397	250	China	1869	541	Sweden	52	81
Sweden	118	197	Sweden	211	366	China	82	64
Italy	275	193	Spain	209	349	Italy	111	63
The Netherlands	110	175	Italy	417	341	The Netherlands	29	52

3.3. Co-Occurrence of Keywords

The co-occurrence network maps of keywords (Figures 5–10) show the main trends and gaps in the investigated area over time. Keywords that are closely connected or clustered together may represent areas of active research and commonly studied topics, while keywords with fewer connections may represent areas where joint research is lacking or underdeveloped.

Based on the literature review, in the Table 5, the initial eight keywords are presented on the topic of "Green infrastructures and Cities", "Ecosystem services and Cities", and "Green infrastructures, Ecosystem services and Cities". The selection was made based on total link strength which means the cumulative strength of connections between keywords: it indicates the overall level of association or co-occurrence between keywords within a dataset.

Comparing network maps of keywords over time can help to track changes in the research landscape and identify emerging trends or shifts in research focus over time. The co-occurrence maps of keywords for the three search combinations are presented and discussed.

Table 5. Top keywords in the three search combinations based on total link strength generated by VOSviewer.

GI and Cities		
Keyword	**Occurrences**	**Total Link Strength**
Green infrastructures	1909	11,040
Green spaces	796	6313
Urban policy	776	5858
Urban areas	643	5659
Climate change	522	3973
Ecosystem services	548	3963
Storms	455	3901
Cities	321	3446
ESs and Cities		
Keyword	**Occurrences**	**Total Link Strength**
Ecosystem services	3517	24,548
Ecosystems	1485	13,586
Urban areas	1086	10,006
Ecosystem	666	8409

Table 5. *Cont.*

Cities	669	7827
Land use	804	7729
Urban policy	914	7358
Urbanization	799	7294
	GI, ES and Cities	
Keyword	**Occurrences**	**Total Link Strength**
Ecosystem services	548	4125
Green infrastructures	470	3229
Green spaces	271	2516
Urban policy	252	2185
Ecosystems	200	2037
Urban areas	192	2012
Cities	105	1322
Urban ecosystem	122	1231

3.3.1. The Scientific Literature on GI and Cities

The co-occurrence analysis of keywords related to "GI and cities" (Figures 5 and 6) resulted in 14,492 keywords of which 148 met a minimum threshold of 40 occurrences.

As an overall trend, the co-occurrence network maps of keywords indicate a more recent focus on air pollution (mainly particulate matter) and urban heat island, with China and Italy as leader countries in this research. Currently, more attention is drawn to cities because of urbanization problems showing concerns on the relation among urbanization, ecosystems, and human well-being. The maps show that the previous focus, before 2020, was on water issues such as flooding, storms, and runoff especially in the United States and the United Kingdom.

More recently, the global scientific literature has been moving onto topics such as urbanization, decision making, urban green spaces, NBS, and air pollution, highlighting the relevance of GI for a more sustainable management of urban systems. Additionally, ESs also resulted as a current topic, emphasizing the relevance of the ecosystem approach in facing urban issues.

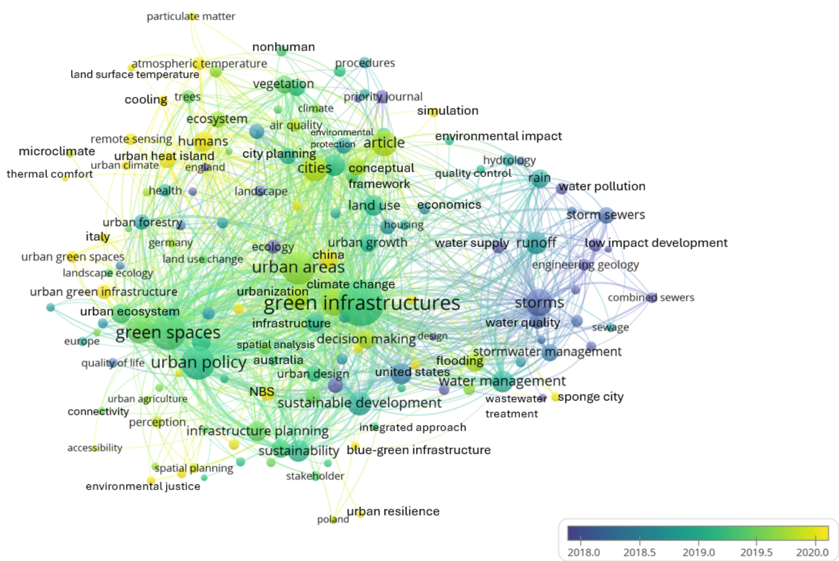

Figure 5. Co-occurrence overlay network map of keywords related to "GI and cities".

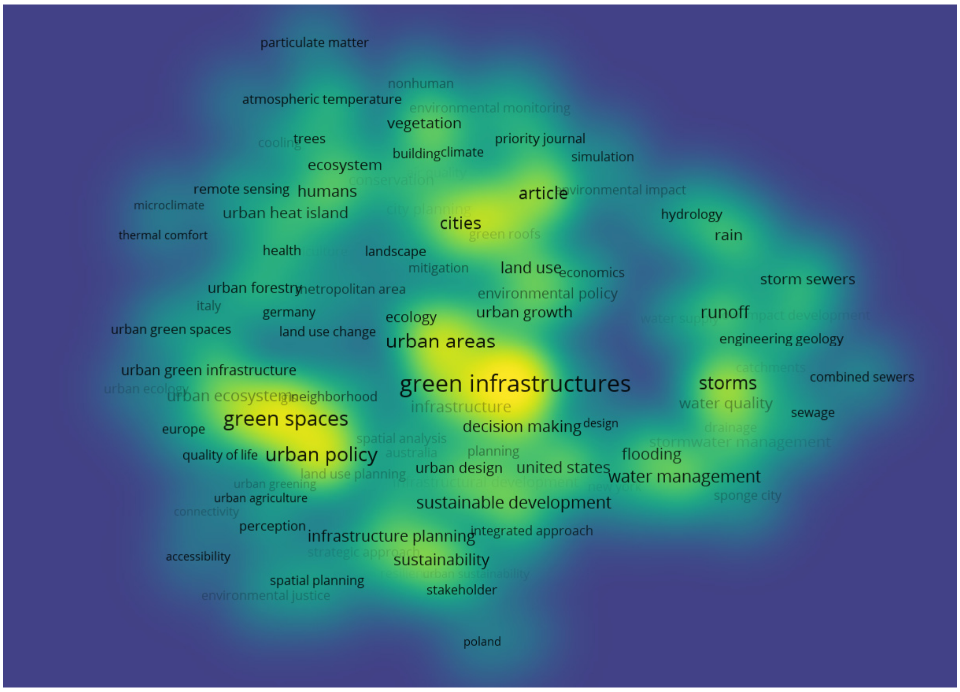

Figure 6. Co-occurrence network density map of keywords related to "GI and cities".

3.3.2. The Scientific Literature on ESs and Cities

The co-occurrence analysis of "ES and Cities" resulted in 20,935 keywords of which 80 met a minimum threshold of 131 occurrences (Figures 7 and 8).

In recent years, trends have shifted to NBS, agglomeration, spatial planning, and cultural ESs as well as to the regulating ecosystem service of carbon sequestration, which is acknowledged as crucial for achieving carbon neutrality. The recent keyword "invest model" also highlights that INVEST has become a popular tool for assessing ESs, complementing GIS tools. In comparison with the first maps on "GI and cities" (Figures 3 and 4), air pollution and urban heat island are still present but not as the most recent topics. Also, in response to Q1, these results demonstrate the important synergy between GI and ESs, as different areas of studies resulted from the separate search on "GI and Cities" and "ES and Cities".

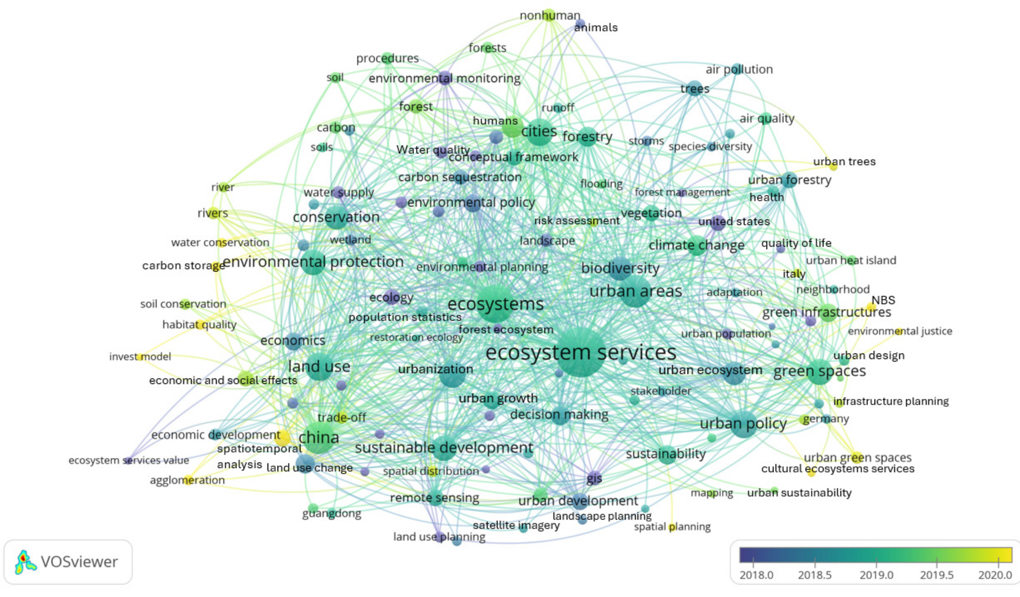

Figure 7. Co-occurrence overlay network map of keywords related to "ES and cities".

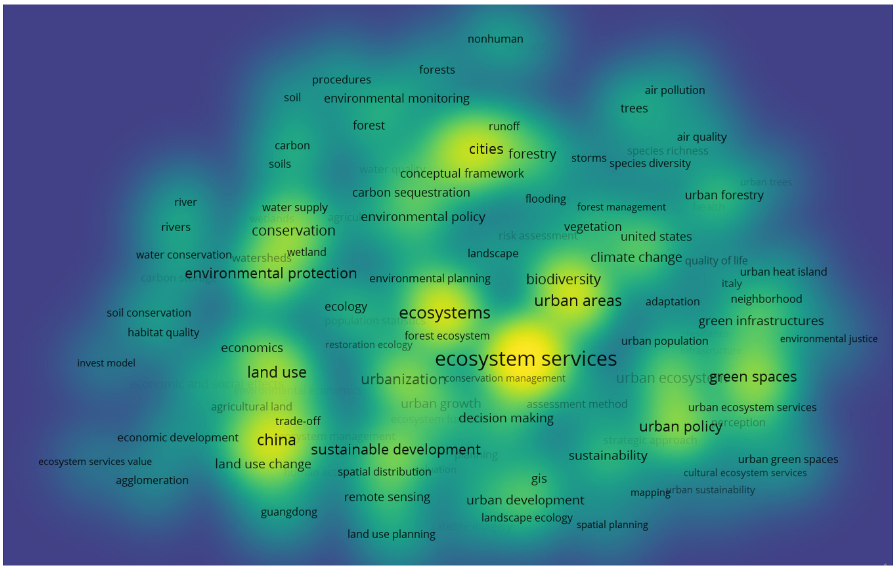

Figure 8. Co-occurrence network density map of keywords related to "ES and cities".

3.3.3. The Scientific Literature on GI, ESs, and Cities

The co-occurrence analysis of keywords (Figures 9 and 10) resulted in 4657 keywords of which 127 met a minimum threshold of 12 occurrences.

When analyzing this map, it is noteworthy that recent attention has been mainly focused on human well-being, urban resilience and urban sustainability, highlighting an increased recent awareness on the important role played by GI and related ESs in achieving sustainable urban systems and for adapting to current environmental problems [73]. Also, it is worth mentioning that there are as equally important topics such as "ecosystem disservices" with China in 2020. According to [74], the examples of ecosystem disservices are plants causing allergies, decreases in air quality, blockage of views, maintenance costs, infrastructure damage, introduction of invasive species, and displacement of endemic species. These are important to assess too as well as ecosystem services, because we usually take into account only benefits for human well-being [75], as even if the plant is removing an air pollutant, it can cause allergies in many people. The keywords "urban trees", "carbon", "mitigation", and "climate change" are also among the most recent ones, suggesting that the increase in GI and generated ESs is being considered in the scientific literature among the urgent actions to face climate change in line with the SDG 13 of the United Nations 2030 Agenda.

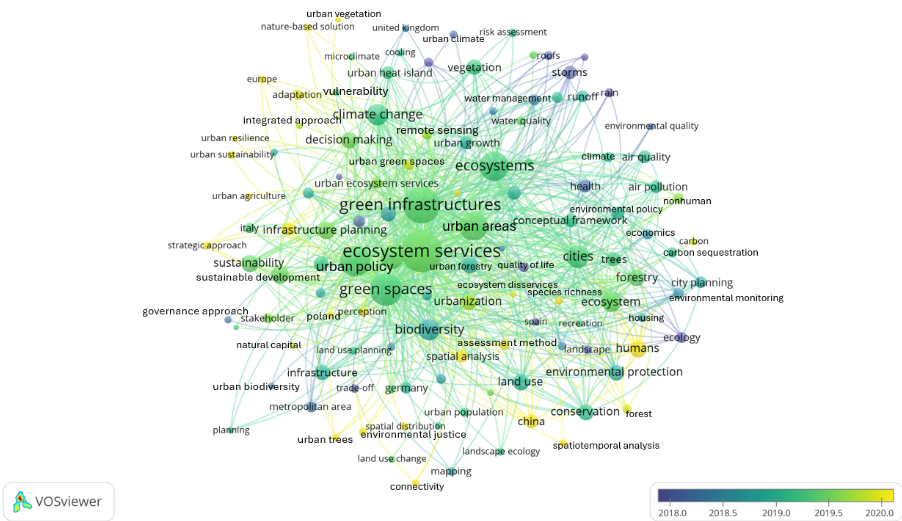

Figure 9. Co-occurrence overlay network map of keywords related to "GI, ES and cities".

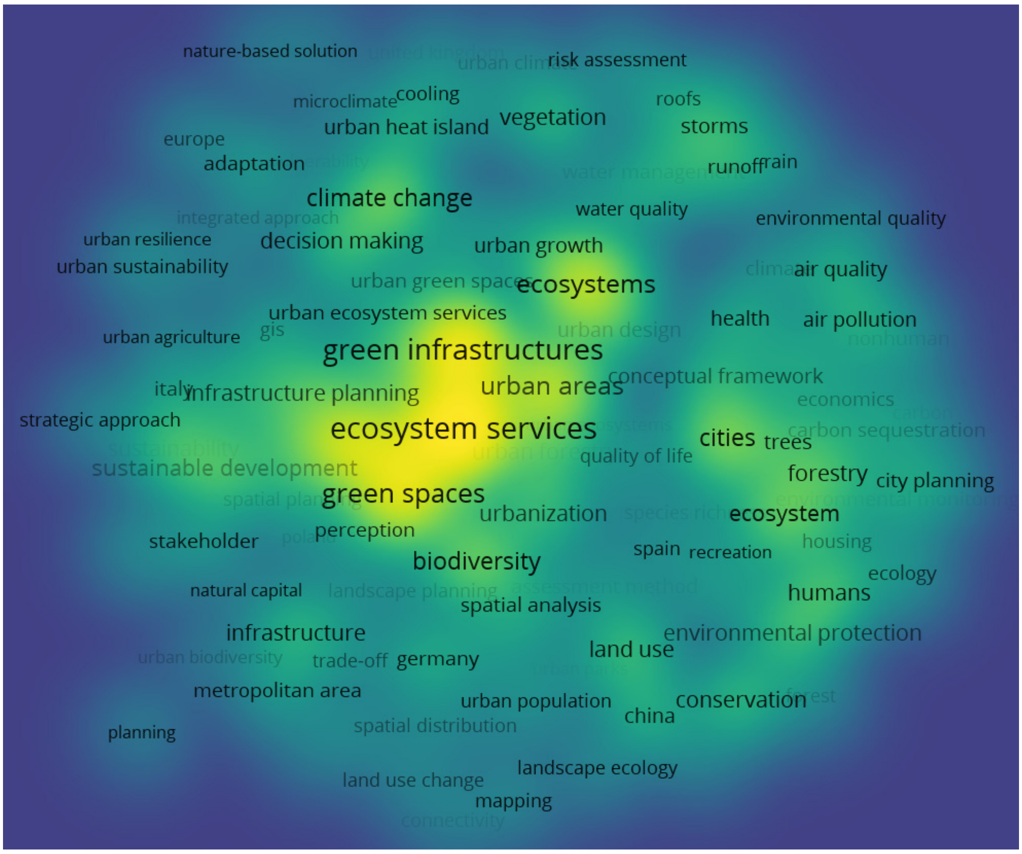

Figure 10. Co-occurrence network density map of keywords related to "GI, ES and cities".

3.4. Citation Network Map of Journals

The citation analysis of journals resulted in an overall number of 293 journals, among which 16 sources met the minimum threshold of 10 articles on the topic of "GI, ES and Cities". The minimum number of citations of a source was identified as three. All journals from this selection based on the number of citations are shown in Table 6. The obtained map highlighted the high number of citations in journals, showing the recent interest on the topic "Green infrastructures, ecosystem services and cities" (Figure 11).

Table 6. Top ten journals based on number of citations on the topic "GI, ES and cities".

Source	Documents	Citations
Urban Forestry and Urban Greening	68	3115
Landscape and Urban Planning	45	3068
Ecological Indicators	23	1579
Environmental Science and Policy	12	1426
Sustainability (Switzerland)	65	1382
Ambio	5	1210
Ecosystem Services	18	1177
Science of the total environment	22	982
Environmental Research	7	928
International Journal of Environmental Research and Public Health	10	699

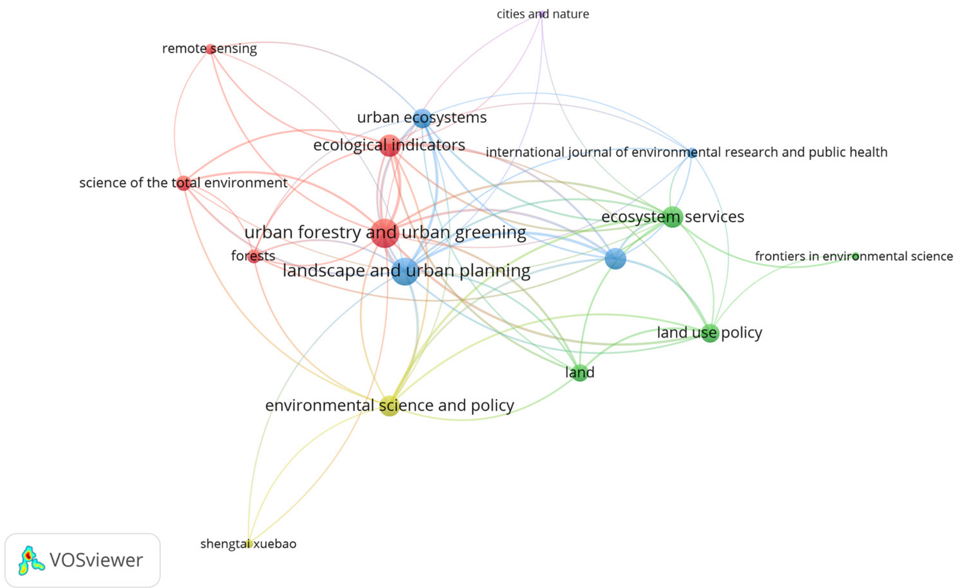

Figure 11. The most cited journals on the topic of "Green infrastructures, ecosystem services and cities".

The results of the citation analysis of the journals reflected the most relevant research domains dealing with "Green infrastructures, ecosystem services and cities", showing the relevance of studies in ecology and urban management. Since 1995, Urban Forestry and Urban Greening (Elsevier) and Landscape and Urban planning (Elsevier) have received the most citations on the topic of "GI, ES and cities".

4. Discussion

This study shows the importance of synergy of the keywords "Green Infrastructure and Ecosystem Services in Cities", and we found several existing studies on the coexistence of the GI/ES research subjects. For example, ref. [39] brought out a gap of economic valuation of ecosystem services and did a comparative analysis of documents from 2010 to 2021. The results of [73] were restricted to the Web of Science with the help of two bibliometric analysis tools, VOSviewer and Biblioshiny. They claim that this study has highlighted the growing interest of the research community in planning GI to promote sustainability in the global context of climate change. The results of this study suggest that GI could become a major strategic factor in addressing the global environmental and social challenges facing cities. Another important observation was the relation between GI with climate change where climate change was clearly among the most recurrent terms. Therefore, from this perspective it is understood that the scientific community positions the use of GI as a tool for adaptation and/or mitigation of the adverse effects of climate change [73,76]. In another example, ref. [42] performed a bibliometric analysis on ecosystem service topics demonstrating a strong link between "ecosystem services" and biodiversity. The top journals in terms of number of highly cited articles were *Ecological Economics*, *PNAS*, and *Ecological Indicators*. Between countries, the US, UK, The Netherlands, Spain, and Sweden were the top five countries in the world in terms of total number of highly cited articles, whereas our research is quite similar with the US and UK as the most consistent. A recent bibliometric analysis conducted by [77], from 2000 to 2023, utilized VOSviewer and CiteSpace for visual analysis using the keyword "island ecosystem services". Their study identified hot topics such as "ecosystem services", "urban heat island", and "climate change", which align closely with our research interests. They also highlighted the "InVEST model", "ecological vulnerability model", and "Google Earth Engine (GEE)" as the most frequently used research techniques and tools. Notably, our study agrees with their findings and observes that the InVEST model is becoming an increasingly popular tool for assessing ESs. In addition, an interesting observation was made in the review paper [78]. The authors divided keywords into four clusters, with one of them being "ecosystem services" and "cities". They highlighted a close connection between green infrastructures and ecosystem services, noting that papers on ecosystem services frequently appear in highly cited literature, emphasizing the importance and relevance of the topic, particularly in urban areas. Furthermore, they identified *Landscape and Urban Planning*, *Urban Forestry & Urban Greening*, and the *Journal of Environmental Management* as the three most frequently cited journals in GI studies. This finding aligns with our study, except for the third journal, which in our case is *Ecological Indicators*.

While previous studies have highlighted the potential benefits of integrating GI and ESs into urban planning, several challenges remain in realizing these goals in practice. Multiple categories of barriers to GI integration have been identified, complicating the process of incorporating both GI and ESs into urban planning. These barriers are **institutional** (due to legal parts such as policies and laws), **regulatory** (due to lack of communication with stakeholders and policymakers), **technical** (challenges in technology implementation), **physical** (limited space and existing land use), **capacity** (lack of funding, resources), and **cultural/community** (due to social perceptions, influence generated by customs, values, beliefs) [79,80].

In this research, we applied a bibliometric network analysis for the identification of the main trends on the following topics: (1) "Green infrastructures and Cities", (2) "Ecosystem services and Cities" and the combined selection (3) "Green infrastructures, Ecosystem services and Cities", using a bibliometric tool, VOSviewer software, and Scopus database. Exploring the global scientific literature, we made a conclusion that singular focuses on either "Green Infrastructures in Cities" or "Ecosystem Services in Cities" provide merely fragmented insights. Instead, the synergistic examination of these domains offers a holistic and broad view: for decision making it is important to consider not only ecosystem services but disservices as well. Moreover, results showed that the research growth on both studied combinations are well fitted to an exponential function.

Research on the topic "GI and cities" showed that there has been a shift from water issues such as flooding, storms, and runoff to more recent topics including air pollution, mainly due to particulate matter, and urban heat island.

Compared to the first search, the second research on "ES and Cities" showed a more recent focus on NBS, cultural ESs and the regulating service of carbon sequestration, which is acknowledged as crucial matter for achieving carbon neutrality.

Finally, the last search on "GI, ES and cities" highlighted a more recent focus on human well-being, urban resilience, urban sustainability and ecosystem disservices. The integration of green infrastructure and ecosystem services has been facilitated by policy frameworks that emphasize nature-based solutions and ecosystem-based approaches to urban challenges. Based on keyword analysis, understanding these synergies has led researchers to investigate how green infrastructure can be designed and managed to maximize ecosystem service delivery. Overall, the shift towards combining green infrastructure and ecosystem services in studies may reflect broader recognition of the interconnectedness between nature, cities, and human well-being. By integrating these concepts and considering both benefits (pest control, pollination) and disadvantages (allergy, disease), researchers, practitioners, and policymakers can develop more effective strategies for building resilient and sustainable urban environments. The following trends and research lines can be an important tool for decision making of urban sustainability globally.

The results also showed that the interaction between green infrastructure and ecosystem services is not as strong as they appear to be separately. Due to GI's younger definition than ES's, it appears that GI and ESs became more synergistic only after 2010. Initially, green infrastructure and ecosystem services were often studied as separate concepts within distinct disciplinary frameworks. Additionally, it is important to note that, as in the study by [44], the first document in our dataset—Scopus—mentioning the term "green infrastructure" dates back to 1995, making it challenging to analyze the earlier literature related to GI under this specific term.

Regarding limitations, we are aware that data such as keywords and authors are quite scarce, it is difficult to provide a concrete overview of the scientific literature, but it helps to understand future lines of research. Also, we only used Scopus search string, and it would be interesting to use other search sources as well. We assume that the future trends are as follows:

- Holistic assessment of all types of green infrastructure (future studies should focus on evaluating the multifunctionality of different GI types beyond forests and parks, including green roofs, wetlands, and sports areas),
- Integration of ecosystem services and disservices, (for example, more studies on cultural ESs [81],
- Importance of biophysical, social, and economic values of ESs,
- More attention to the problem of urban heat island, and
- More engagement with stakeholders and policymakers for better urban planning.

In conclusion, this study highlighted that GI and related ESs are becoming core concepts and tools to address urbanization concerns and achieve urban sustainability. Indeed, the integration of GI in cities can benefit human well-being, biodiversity, and reduce the way cities impact their surroundings, creating more livable systems.

5. Conclusions

The integration of green infrastructure and ecosystem services has been increasingly facilitated by policy frameworks that emphasize nature-based solutions and ecosystem-based approaches to urban challenges. This shift reflects a broader recognition of the interconnectedness between nature, cities, and human well-being. Through bibliometric analysis, strong connections have emerged between GI, ESs, and urban settings, as well as the growing importance of nature-based solutions in addressing these relationships.

However, a significant gap remains in the research: not all types of GI are equally studied or recognized for their potential to provide ecosystem services. While some GI types, like urban forests and parks, are well-explored, others such as green roofs, sports areas, and wetlands are often overlooked despite their multifunctionality. Understanding the human well-being and ecosystem services provided by under-researched GI types is critical to filling this gap. In particular, more attention should be given to cultural ecosystem services—which contribute to mental health, recreation, and social well-being—but these remain underexamined, compared to other ESs, and are often undervalued in the broader context of GI and ESs research.

Additionally, there is a growing need for a more balanced approach that considers not only the benefits (e.g., pollination, pest control) but also the potential disservices (e.g., pollen allergy, disease). This nuanced understanding will enable policymakers and urban planners to create more resilient and sustainable urban environments that benefit both people and biodiversity.

Future research should integrate biophysical, social, and economic values to provide more holistic insights for sustainable urban development. While biophysical values of ecosystem services are essential, they may not fully support urban planning decisions on their own. Economic valuation is crucial for policymakers, offering tangible data on the financial benefits of ESs.

By integrating these concepts and focusing on a holistic approach to GI and ESs, cities can become more livable, fostering well-being while mitigating the environmental impacts of urbanization. This evolving synergy between GI, ESs, and human well-being highlights a promising direction for future research and policy aimed at building sustainable, resilient cities.

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