The multi-functional value of urban green infrastructure: a comprehensive and systematic review

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La valeur multifonctionnelle des infrastructures vertes urbaines: une révision complète et systématique

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RÉSUMÉ

Les solutions basées sur la nature sont étudiées depuis des décennies et considérées dans le monde entier comme des alternatives prometteuses pour des systèmes de drainage urbain plus durables et efficaces. Cependant, il existe encore une certaine réticence à son adoption, en raison de ses coûts et de sa complexité supposés d'être plus élevés. Dans cette étude, nous examinons la vue d'ensemble pour ajouter des preuves sur tous les services écosystémiques fournis par l'infrastructure verte urbaine, soutenant le débat public et les décisions des gestionnaires fonciers sur son adoption. L'examen systématique a pris en compte la recherche de mots-clés liés aux méthodes de quantification des services écosystémiques fournis par les infrastructures urbaines vertes et bleues, et 742 études ont été sélectionnées pour analyse. La plupart des études provenaient de chercheurs affiliés à des institutions du Nord Global ; les techniques les plus étudiées sont les espaces verts urbains et les toits verts; les avantages les plus fréquents étaient liés à la qualité du climat, socioculturelle et de l'eau ; les méthodes les plus courantes sont le SIG et la surveillance, appliquées à l'échelle spatiale des villes et des quartiers. Les principales lacunes identifiées sont liées à l'estimation des avantages multiples fournis par les IVB, aux études comparant les réalités du Nord et du Sud Globales et aux études évaluant les services écosystémiques des espaces verts intégrés à la végétation riveraine et aux techniques DBI.

ABSTRACT

Nature Based Solutions or Low Impact Development techniques such as green roofs, permeable pavements, bioretention systems, among others, have been studied for decades and considered worldwide as promising alternatives for more sustainable and effective urban drainage systems. Even so, there is still some reluctance to its wider adoption by public and private decision makers, especially in the Global South, due to its supposed higher costs and complexity compared to traditional stormwater control measures. In this study, we look to the big picture to add evidence on all ecosystem services provided by the Urban Green Infrastructure, supporting public discussion and land managers' decisions on adopting LID. The systematic review considered research of keywords related to quantification methods of ecosystem services provided by urban green and blue infrastructure, and 742 studies were selected for analysis. Most studies came from researchers affiliated to institutions from the Global North; the techniques most frequently studied are urban green areas and green roofs; the most frequent benefits were related to climate, socio-cultural and water quality; methods most common are GIS and monitoring, applied in the spatial scale of cities and neighborhoods. Main gaps identified are related to the estimation of multiple benefits provided by LID, studies comparing Global North and South realities, and studies evaluating ecosystem services of green areas integrated with LID and urban waters.

MOTS-CLÉS
Services écosytémiques, infrastructure verte, révision systématique, quantitative, solutions basées sur la nature.

KEYWORDS
Ecosystem services, green infrastructure, systematic review, quantitative, nature-based solutions.

1 INTRODUCTION

The term 'Green and Blue Infrastructure' (GBI) is one of several terms used to refer to alternative and sustainable approaches in the context of stormwater management and urban drainage, among other expressions as 'Green Infrastructure' (GI), 'Water Sensitive Urban Design' (WSUD), 'Low Impact Development' (LID), 'Alternative Techniques', 'Source Control', 'Sustainable Urban Drainage Systems' (SUDS), 'Best Management Practices' (BMPs), etc. These concepts were developed in different locals and contexts and, although there are some differences in their specificity and focus, most of them can be applied in the urban context (Fletcher et al., 2015). One of the terms with the greatest recent increase in popularity is 'Nature-Based Solutions' (NBS), since the resounding consideration of them as leading measures for climate change adaptation in the United Nations Conferences of Parties (COP) 25 and 26 (Miles et al., 2021). Following the conferences, however, many organizations criticized the indiscriminate embrace of NBS in the discourse as the main strategies for climate adaptation, especially focusing in NBS potential on carbon sequestration and storage, often taking the focus away from the control of GHG emissions by the consumption of fossil fuels. Even so, many studies emphasize the importance of the many benefits of NBS for social and ecological adaptation to climate change (Seddon, 2022).

Some institutional mechanisms can be used to incentivize NBS implementation in city scale: land use zoning, building codes, landscape ordinances, and environmental statutes (Foster et al., 2011). Political support is also crucial for wide GBI deployment, eitherby governments and decision makers in a top-down-driven, or through broad civic support and community engagement, in bottom-up driven effort (Wouters et al., 2016). Nevertheless, large-scale applications are often limited by economic unfeasibility, although GBI are becoming increasingly used in cities especially in the Global North (and China) as stormwater management solutions (Vincent et al., 2017). In this context, the aim of this study is to look for evidence about the potential of NBS-GBI to improve cities' resilience against some impacts of climate change (extreme rainfall events, e. g.), and urban development (urban heat island effect, e. g.), as well as in the provision of many ecosystem services and their contribution to increase the wellbeing and cities livability. The objectives of this review are to explore how the benefits of Green Infrastructure are being quantified, analyzing: 1) the time evolution of interests, terms, and methods; 2) geographic distribution of research topics and methods; 3) most frequently benefits quantified for each GI type; 4) methods and indicators applied for the study of each benefit; 5) spatial scale of studies according to methods and benefits studied.

2 METHODS

The systematic review followed an adapted version of the guidelines proposed in PRISMA 2020 – "Preferred Reporting Items for Systematic reviews and Meta-Analyses" (Page et al., 2021). The keywords indicated in Table 1 were searched in Scopus and Web of Science database on 14 June 2022 and consisted solely of peer-reviewed works published in English language and available using institutional access. After the screening of Title, Abstract and Full Text, 742 studies were selected for classification according to geography, scale, terminology, techniques, benefits, method, and indicators.

Table 1 - Keywords searched in the Scopus and Web of Science databases, with no restriction of year of publication, and considering the keywords "*urban*" and "*quantitative*"

Terms		Benefits		Methods
"green and blue infrastructure" (GBI) ***or*** *"green infrastructure" (GI)* ***or*** *"best management practices" (BMP)* ***or*** *"integrated urban water management" (IUWM)* ***or*** *"low impact development" (LID)* ***or*** *"source control" (SOC)* ***or*** *"stormwater control measures" (SCM)* ***or*** *"sustainable urban drainage system" (SUDS)* ***or*** *"water sensitive urban design" (WSUD)* ***or*** *"urban canopy" (UCAN)* ***or*** *"urban green areas" (UGAS)* ***or*** *"green corridors" (GCOR)* ***or*** *"sponge city" (SPC)* ***or*** *"green roof" (GR)*	**&**	*"heat island"* ***or*** *"climate regulation"* ***or*** *"temperature regulation"*	**&**	*"ecosystem services"* ***or*** *"economic"* ***or*** *"value"* ***or*** *"valuation"* ***or*** *"cost-benefit"*
		"air quality" ***or*** *"air pollution"* ***or*** *"ozone"* ***or*** *"particulate matter"*		
		"carbon emission" ***or*** *"carbon sequestration"* ***or*** *"carbon storage"* ***or*** *"greenhouse gas"*		
		"health" ***or*** *"social"* ***or*** *"leisure"* ***or*** *"activity"* ***or*** *"recreation"*		
		"agriculture" ***or*** *"food production"*		
		"water quality" ***or*** *"water pollution"* ***or*** *"diffuse pollution"* ***or*** *"non-point source solution"*		
		"water quantity" ***or*** *"runoff"* ***or*** *"infiltration"* ***or*** *"flood"* ***or*** *"water security"* ***or*** *"water supply"* ***or*** *"stormwater"*		

3 RESULTS

The top ten countries with the greatest number of affiliated authors were: United States of America (144 studies), China (86), Italy (57), United Kingdom (53), Australia (43), Germany (34), Spain (32), Brazil (24), South Korea (17), and Portugal (14). Figure 1 shows the frequency of collaboration among authors from different nations, where the wider the line, the greater the number of collaborations.

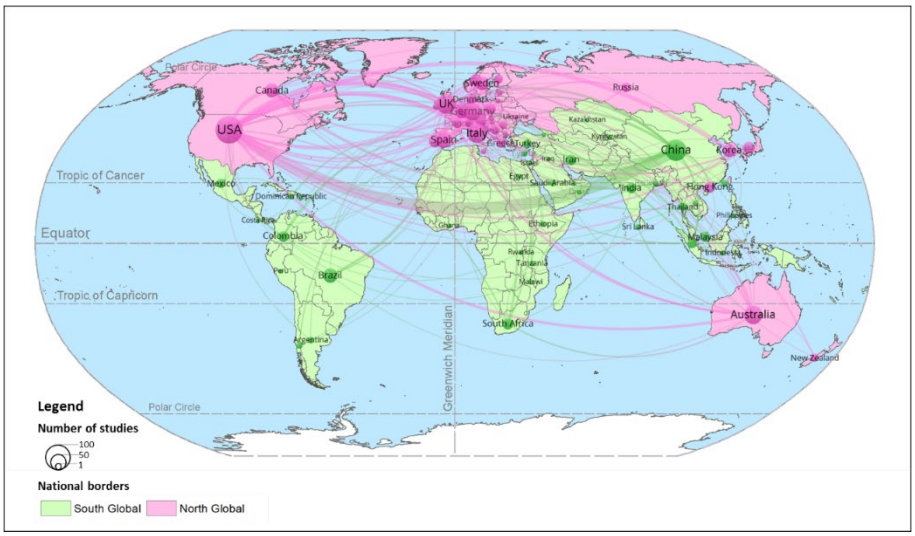

Figure 1 - International collaboration in publication (wider lines indicate greater collaboration), distinguishing North (pink color) and South (green color)

Most studies were developed in countries from the Global North (599 studies), and the map highlight the great collaboration between North America and Europe. China is the greatest South Global research partner with institutions from the Global North, but there is a clear gap of research comparing North-South realities and discussing similarities and specificities of developing countries, especially from tropical countries in Latin America, Africa, South and Southeast Asia. Some differences between Global South and North were identified in the frequency of themes and interests. The term “Green Infrastructure”, for an example, is used more frequently in Global North (53% of studies) than in Global South (31% of studies); and the benefits related to “water quantity” are more frequently studied in Global South (43%) than Global North (32%); while “air quality” is more frequently studied in North (34%) than in South (17%).

The software VosViewer was used to produce the network map in Figure 2 (Eck & Waltman, 2010).

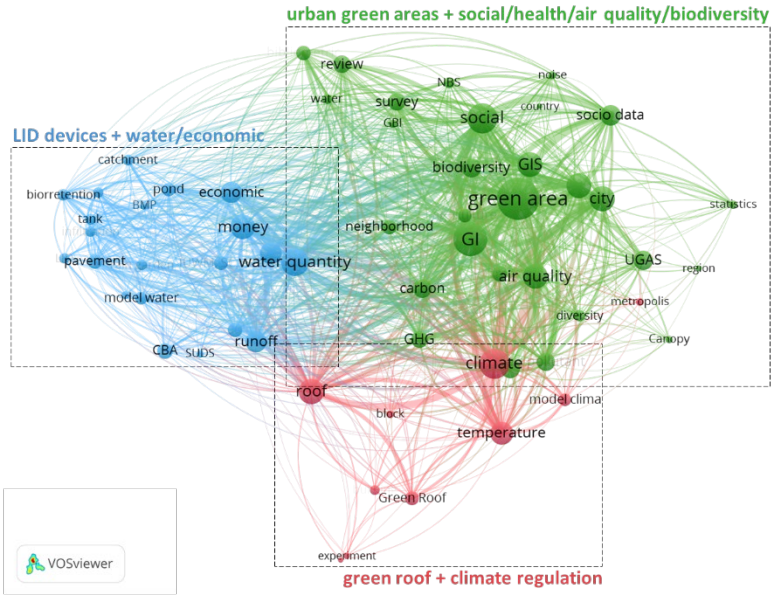

Figure 2 - Network map between terminology, techniques, methods, and benefits (using filtered classified data)

Three ‘clusters’ of research areas can be identified in the network map developed using the classified and coded data extracted from the selected studies. First, indicated in blue in Figure 2, is the group of 159 studies focused on techniques mainly applied for stormwater control as bioretention cells, retention ponds, permeable pavements, and rainwater harvesting tanks. Most of these studies use terms as SUDS, LID, and BMP, and usually quantify just the water-related benefits, that are runoff and flood control, rainwater harvesting for reuse, and diffuse pollution treatment. These are also the studies that most frequently follow an economic evaluation of costs and benefits of these infrastructure. The second cluster, indicated in red in Figure 2, consists of 138 studies focused on green roofs that usually assess the benefits of temperature regulation and mitigation of urban heat island. The most frequent methods applied are experiment (mainly in pilot or building scale) and climate modelling (from building to city scale). The third cluster, indicated in green in Figure 2, encompasses the 555 studies that assess many social and environmental benefits of urban green areas, as improvement of socio-cultural aspects, creation of recreation and leisure opportunities, health and air quality improvement, biodiversity protection, etc.

4 CONCLUDING REMARKS

This study is part of a greater research which main objective is to support public discussion and decision-making on adoption of GBI, providing evidence about its economic viability and social support, considering all the ecosystem and environmental services they provide, especially for the protection of water resources, the reduction of damage caused by floods and the social and environmental benefits they promote. The systematic review briefly presented in this abstract brings many insights about the state of art and the global interests on the topic, highlighting the gaps and potential for collaboration and transference of technology and knowledge among different countries and contexts. The next steps of this research are the discussion on valuing traditional and local knowledge about nature-based solutions on urban land and water management context, as well as the presentation and dissemination of evidence on the multiple benefits of GBI especially for managers and local governments.

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