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Green Infrastructure and basic sanitation: parallels, benefits and the potential of implementation through the Municipal Plans

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Authors' notes'

The authors have no conflicts of interest to declare.

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Abstract

Objective: This work establishes parallels between elements of Green Infrastructure (GI) and basic sanitation services stipulated in the National Basic Sanitation Policy, and highlights possible benefits/functions of GI for each of these services, discussing the role of Municipal Basic Sanitation Plans (MBSP) in this context.

Methodology: A bibliographical review and public policy analysis were carried out by studying the content of related legislation.

Originality/relevance: The paper includes the development of a framework relating the elements of GI and their potential benefits/functions in relation to the different elements of sanitation, in addition to the issue of water and sewage, more commonly related to GI in the literature, collaborating in a more comprehensive way for the discussion.

Results: It is concluded that the environmental services provided by a GI network can contribute to greater sustainability of basic sanitation networks, thus highlighting the importance of GI being included in policy-making. In this sense, the MBSP have the potential to stimulate and subsidize the planning and implementation of GI by municipalities.

Social/Management Contributions: Considering the current situation of basic sanitation in Brazil, the opportunity to use GI is discussed as a way to assist the provision of basic sanitation services in a more sustainable way and with a series of social, environmental and economic benefits. Linking these alternative solutions in the design of MBSP, mandatory for all municipalities, increases the opportunity for these solutions to be put into practice, in a complementary way to the gray infrastructure solutions.

Keywords: Municipal Basic Sanitation Plan, public policy, environmental services, networks

Infraestrutura verde e saneamento básico: paralelos, benefícios e o potencial de implementação por meio dos Planos Municipais

Resumo

Objetivo: O presente trabalho estabelece paralelos entre elementos de Infraestrutura Verde (IV) e os serviços de saneamento básico, estipulados na Política Nacional de Saneamento Básico, e evidencia possíveis benefícios/funções das IVs a cada um destes serviços, discutindo o papel dos Planos Municipais de Saneamento neste contexto.

Metodologia: Foi realizada revisão bibliográfica e análise de política pública mediante o estudo de conteúdo das legislações relacionadas.

Originalidade/relevância: O trabalho inclui a elaboração de um quadro relacionando os elementos de infraestrutura verde e seus potenciais benefícios/funções frente aos diferentes elementos do saneamento, para além da questão da água e do esgoto, mais comumente relacionados à IV na literatura, colaborando de forma mais abrangente para a discussão.

Resultados: Conclui-se que os serviços ambientais providos por uma rede de IV podem contribuir com a maior sustentabilidade das redes de saneamento básico, destacando-se assim a importância da IV estar inserida no contexto de política pública. Neste sentido, os PMSB apresentam o potencial de estimular e subsidiar o planejamento e a implementação de IVs pelos municípios.

Contribuições sociais/para gestão: Tendo em vista a situação do saneamento básico no Brasil, discute-se a oportunidade de utilização de IV como forma de auxiliar na provisão dos serviços de saneamento básico de forma mais sustentável e com uma série de benefícios sociais, ambientais e econômicos. Atrelar estas soluções alternativas no delineamento de PMSB, obrigatórios para todos os municípios, aumenta a oportunidade de estas soluções serem colocadas em prática, de forma complementar às soluções de infraestrutura cinza.

Palavras-chave: Plano Municipal de Saneamento Básico, política pública, serviços ambientais, redes

Infraestructura Verde y saneamiento básico: paralelos, beneficios y potencial de implementación a través de los Planes Municipales

Resumén

Objetivo: Este trabajo establece paralelismos entre elementos de Infraestructura Verde (IV) y servicios de saneamiento básico estipulados en la Política Nacional de Saneamiento Básico, y destaca posibles beneficios/funciones de la IV para cada uno de estos servicios, discutiendo el papel de los Planes Municipales de Saneamiento Básico (PMSB) en este contexto.

Metodología: Se realizó una revisión bibliográfica y un análisis de políticas públicas mediante el estudio del contenido de la legislación relacionada.

Originalidad/relevancia: El documento incluye el desarrollo de un marco que relaciona los elementos de la IV y sus beneficios/funciones potenciales en relación con los diferentes elementos del saneamiento, además de la cuestión del agua y el alcantarillado, más comúnmente relacionados con la IV en la literatura, colaborando en un manera más completa para la discusión.

Resultados: Se concluye que los servicios ambientales proporcionados por una red de IV pueden contribuir a una mayor sostenibilidad de las redes de saneamiento básico, destacando así la importancia de que la IV sea incluida en el contexto de las políticas públicas. En este sentido, los PMSB tienen el potencial de estimular y subsidiar la planificación y implementación de IG por parte de los municipios.

Contribuciones sociales/de gestión: Considerando la situación actual del saneamiento básico en Brasil, se discute la oportunidad de utilizar la IV como una forma de ayudar en la prestación de servicios de saneamiento básico de una manera más sostenible y con una serie de beneficios sociales, ambientales y económicos. Vincular estas soluciones alternativas en el diseño del PMSB, obligatorio para todos los municipios, aumenta la oportunidad de que estas soluciones se pongan en práctica, de forma complementaria a las soluciones de infraestructura gris.

Palabras clave: Plan Municipal de Saneamiento Básico, política pública, servicios ambientales, redes

Introduction

The universalization of basic sanitation, scheduled for 2033 in accordance with Law 14026/ 2020, is certainly one of the biggest challenges to be faced in Brazil. It stands out as a complex and urgent issue that requires improved management, including planning, administration, instruments and tools. Also essential are practices to promote structural, economic, environmental and, consequently, social advances, meeting the basic needs of individuals and enabling more dignified living conditions.

The context of sanitation in Brazil is indeed challenging. Data from Instituto Trata Brasil (2021) indicate that, in 2021, around 15% of Brazilians had no access to treated water and 44.2% lacked sewage collection. In addition, only 51.2% of the sewage collected was treated (treated sewage/generated sewage ratio). Still according to this survey, the number of deaths due to waterborne diseases was also alarming, 1493 reported in that same year (2021).

In turn, among the Sustainable Development Goals (SDGs) of the UN 2030 Agenda is SDG 6, aimed at achieving universal and equal access to safe drinking water (United Nations [UN], 2023). This SDG is to "Ensure the availability and sustainable management of water and sanitation for all" (UN, 2023) and, like the others, it has great potential for guiding public policy and decision-making by managers in the different areas of this challenge.

In Brazil, an important tool aimed at helping improve sanitation is the Municipal Basic Sanitation Plan (PMSB). This document is mandatory for all municipalities and set guidelines for sanitation initiatives to be implemented in accordance with the local reality, as provided by legislation. The Municipal Master Plan (FUNASA, 2012) should also be observed, thus establishing, albeit indirectly, a relationship with the guidelines for land use and occupation.

Also prominent in this regard is Green Infrastructure (GI), a relatively recent concept that relates to an interconnected network of natural and semi-natural elements to be strategically planned and implemented at different scales, fulfilling different functions, such as the provision of environmental and/or ecosystem services (Benedict & McMahon, 2006; EC, 2014; Sant'Anna, 2020; Van der Sluis and Jongman, 2021; Santos & Freiria, 2023).

These infrastructures comprise elements that have shown potential synergy relationship and direct interaction with issues related to sanitation, such as constructed wetlands, used in sanitary sewage treatment and also in water management, especially urban drainage and supply (Stefanakis, 2019).

Considering this possible synergy between GI and sanitation, this work seeks to establish connections between GI elements found in the literature and the basic sanitation services provided in the National Policy for Basic Sanitation, highlighting how GIs may provide benefits and/or fulfill functions for each one of those services. Bearing in mind that GIs are multifunctional structures with lower environmental impact, since they essentially rely on natural elements, the opportunity to address sanitation needs through projects and actions from this perspective enables improvements in environmental quality, especially in urban centers, providing solutions to urgent sanitation needs.

It is also important to align the planning of GIs, as interconnected networks, and of sanitation services with strategic plans, especially with regard to interference in land use and occupation, reflected in guidelines for new developments such as Municipal Master Plans (Santos & Freiria, 2023). They should also be aligned with PMSBs, thus promoting the implementation of GI elements within the execution of projects provided in the plan. Additionally, according to the National Policy for Basic Sanitation, Municipal Basic Sanitation Plans are the responsibility of municipalities, with the support from states (Brasil, 2020). Therefore, such plans must comply with guidelines from supra-municipal policies and plans, with coordination across different levels being essential.

It should be noted that government initiatives are key to the introduction of GIs as viable alternatives, especially in developing countries, even more so to encourage society to adopt them. Therefore, promoting the adoption of sustainable strategies, greener cities and better quality of life and social conditions should be embedded in public policies (Liberalesso et al., 2020).

Literature review

The National Policy for Basic Sanitation (PNSB) and Municipal Basic Sanitation Plans (PMSB)

As a social need, sanitation was initially related to public health. It directly interfered in urban planning in the early 20th century and later guided public policies targeting more specific sectors and services. The first Policy for Basic Sanitation in Brazil was established in 1967, setting guidelines for water supply and sanitary sewage (Freiria, 2011). The Federal Constitution of 1988, in turn, addresses the subject in three of its articles (Articles 21, XX, 23, IX and 200, IV). Thus, it can be linked to urban development and public health, being a basic right of all and object of specific public policies (Freire, 2020).

Currently, Law 11445/2007, amended by Law 14026, dated July 15, 2020, which provides the legal framework for sanitation, defines basic sanitation as a set of services, infrastructures and operational facilities for the supply of drinking water, sewage sanitation, urban cleaning and solid waste management, in addition to drainage and management of urban stormwater. This legislation provides the obligation to formulate basic sanitation plans at local or regional level.

The National Policy for Basic Sanitation (PNSB) should be implemented by the entity responsible for the sanitation service, namely the municipality, with the assistance of the state. Each municipality must, therefore, prepare a PMSB or be included in the context of the regionalized plan. The Plans must contain at least the diagnosis of the situation, the objectives and goals, the programs, projects and actions, emergency and contingency actions and systematic evaluation mechanisms, as provided by the legislation.

In January 2020, the obligation to prepare PMSBs was extended to December 2022, after four previous extensions. Although this deadline has already expired, there has been no legislative change defining a new extension. This means that, in theory, municipalities that have not implemented their respective plans are prevented from accessing federal funds aimed at basic sanitation.

The latest data processed by IBGE on the percentage of municipalities that have met the deadline established by PNSB are from 2017 (IBGE, 2018). Such data indicate that in 2017, 2,313 Brazilian municipalities (41.5% of the total) had a Municipal Basic Sanitation Plan. In regional terms, the states with the highest percentage of municipalities with said plan were

Santa Catarina (87.1%) and Rio Grande do Sul (75.5%), while the lowest rates were found in Paraíba (13.0%), Pernambuco (14.1%) and Bahia (14.6%).

PMSBs are considered vital instruments for the strategic planning of cities, serving as examples of public policies that are key to enhancing management. That is because they provide support to managers for more assertive, effective and efficient decision-making, considering the entire extent of the area in order to meet the specific and/or shared needs and interests of society (SEBRAE/MG, 2008, p. 5). It is also one of the main tools for organizing the management of sanitation services, since regulatory activities and contracts for the provision of these services must necessarily comply with the provisions of the aforementioned Plan (Brasil, 2013).

Green infrastructures

Given the complexity of the environmental challenges, impacts and violations of vital rights, individual and collective measures are urgently needed to promote the improvement of this situation. The only way to reduce the negative consequences of human actions is by modifying the way we relate to the planet. The pursuit of harmony and coexistence with the environment and of the improvement and resilience of communities is essential for our survival as a species.

In view of this context, in the search for "[…] innovative and sustainable solutions based on concepts of environmental design and landscape ecology" (Hannes, 2015, p.56), nature-based solutions (NBS) stand out.

According to the European Commission (European Commission, 2015), NBS are actions supported or inspired by nature, capable of promoting adaptation and resilience and offering social, economic and environmental benefits, since they revive different natural processes and aspects for both urbanized areas and modified or natural ecosystems to be restored.

Understood as an umbrella concept, SBN include different approaches: ecosystem protection approaches; specific approaches related to ecosystems; infrastructure-related approaches; ecosystem-based management approaches; ecosystem restoration approaches (Cohen-Shacham et al., 2016). In this context, the concept of GI can be viewed as a form of nature-based solution, even if it predates its emergence.

In this sense, publications, official documents and structural initiatives that aim to appreciate and integrate nature with man and the built landscape have been launched and implemented since the 19th century, highlighting the idea of GI that optimizes land occupation by considering social needs, while seeking to reduce the impacts already caused (Benin & Constantino, 2017).

It is worth mentioning the definition presented by the European Commission, which describes GI as “a strategically planned network of natural and semi-natural areas with other environmental features, designed and managed to deliver a wide range of ecosystem services” (European Commission, 2014).

Considering that the term GI may have different meanings depending on the context, this work follows the definition of “an interconnected network of natural areas and other open spaces that preserves natural ecosystems’ values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife” (Benedict & McMahon, 2006), acting at different scales (landscape, project/private, individual, local, state, national) according to need and planning (IPT, 2020; Sant'Anna , 2020; Prescott et al., 2021).

GI comprises a system of hubs, links and sites. The hubs anchor the GI networks and provide space for the life of plants and animal communities, i.e., they are the origin or destination of animals and ecological processes that move through the system. Examples of hubs are: large reserves and protection areas; large public areas, such as national and state forests; private areas, such as farms; regional parks and reserves; community parks and green spaces. The links are the connections that “tie” the system together. They are essential for maintaining vital ecological processes and the health and biodiversity of animal populations. In addition, they have great potential for recreational use by the population. Examples of links are:

rivers, floodplain areas, greenways, ecological corridors and green belts. The sites are smaller than the hubs and may not be connected to the network, but they contribute to important ecological and social values such as protection of animal life and recreational use (Benedict & Mcmahon, 2006; Benini & Constantino, 2017).

Vasconcellos (2015) proposed a method for applying a GI: 1. Identify possible hubs; 2. Define the minimum size of the hubs; 3. Eliminate pre-selected hubs below the minimum size; 4. Identify the landscape type of each hub and the potential connections between them in order to replicate the natural ecological patterns of the area; 5. Identify appropriate and inappropriate areas to create links; 6. Define the most suitable areas, based on the pre-selection made in step 5; 7. Evaluate whether the selected areas make up a continuous pathway and have the necessary width to support the network ecologically; 8. If not, investigate whether it is possible to restore the modified areas to natural spaces that will fill the gaps in the links; 9. If restoration is not possible, eliminate those previously selected areas; 10. Evaluate the pros and cons of each connection and determine the network design.

As core principles of a GI, Benedict and McMahon (2006), the first authors to mention GI, argue that: connectivity is the key; context matters; it must be scientifically grounded; it can and should function as a network for conservation and development; it must be planned and protected before development; it is an essential public investment; it provides benefits to nature and people; it respects the needs and desires of landowners and other stakeholders; it requires connections to activities within and outside the community; it requires long-term commitment. Regarding urban GI, Marques (2020) highlighted six principles: multifunctionality; connectivity; green-gray integration; multiple scales; importance of context and transdisciplinary process.

GIs facilitate holistic views and responses to the different needs imposed by cities; they require communication, planning and participation from all interested/impacted parties (people, communities and/or sectors); they are NBS, generally of low cost; they must be distributed, varied, decentralized and integrated; they form networks composed of elements adapted to each context; and having multiple shapes, materials and sizes, they fulfill multiple functions on different scales; are more resilient; contribute to the circular economy and the design of better policies, which in turn can guide the design and installation of these structures in municipalities (Vollmer & Gret-Regamey, 2013; Ferreira et al., 2013; Eger & Stein, 2015; Dong et al., 2017; Douglas, 2018; Vörösmarty et al., 2018; Langergraber & Masi, 2018; Tao, 2019; Herslund & Mguni, 2019; ASCE, 2019; Nzimakwe, 2020; Poosti et al., 2020; Martín et al., 2020; Thakur & Bhonde, 2021; Mesgar et al.2021; Cheshmehzangi et al., 2021; Prescot et al., 2021; Bridgewater, 2021; Bertrand-Krajewski, 2021; Faedda & Plaisant, 2021; Franco-Torres et al., 2021; Dal Ferro et al., 2021).

As a conception of planning and development, the term GI has spread in fields of study, discussions and projects implemented by different areas and professionals around the world. More efficient and effective interventions require knowledge about local specificities and the limitations and potential of technologies for each reality, dynamism, flexibility, systemic approach, inter, multi and/or transdisciplinarity, in addition to information and participation of the community affected by the proposal (Herzog & Rosa, 2010; Benini & Constantino, 2017; Braga & Gouveia, 2020; Benini & Rosin, 2019).

Prominent among the various benefits provided by the elements of GIs is the provision of environmental and ecosystem services. The Millennium Ecosystem Assessment (UNEP, 2005) defined ecosystem services as all benefits that people can obtain from the environment (ecosystems), including provision, regulatory, cultural and support services. Environmental services, in turn, would be the benefits arising from human intervention, restoring and/or enhancing ecosystem services and consequently life in general (Ferreira et al., 2013; IPT, 2020).

Santos and Enokibara (2021) present “a classification of the terms most commonly used to refer to GI typologies” in Brazilian publications, highlighting: green corridors, linear parks, open spaces, natural areas, rain gardens, urban tree-planting, bioswales, ecological corridors, rainwater beds, constructed wetlands, green roofs, rainwater ponds, permeable floors, permeable fragments, green paths, green belts, tree-lined streets, retention basins, greenways, cisterns, green networks and green streets.

The authors also emphasize some GI-related terms directly associated with basic sanitation: Best Management Practices (BMP); bioengineering; biomimetics; bioretention; root zone treatment; phytodepuration; phytoremediation; Low Impact Development (LID); Sustainable Urban Drainage Systems (SUDS); Compensatory Techniques (CT) (Santos & Enokibara (2021).

Methodology

In a survey of the scientific literature, a systematic search was carried out on July 6 and August 12, 2022 in two databases, Scopus and Web of Science (WoS). Both have millions of indexed documents and provide international visibility for research and scientific production.

Considering the interest in publications also from Brazil, it was decided to search for documents in Portuguese and English, the latter being the agreed-upon language for common scientific communication. On the other hand, aiming for more recent scientific publications, the time span was limited to five years. Using the keywords "*infraestrutura verde*" and "green infrastructure," and selecting reports between 2017 and 2022, 2,894 documents were obtained in Scopus (62 from Brazil) and 2,969 in WoS (74 from Brazil). Aiming to refine the results, a new search was carried out on October 13, 2022, with no defined time span, as the survey was already limited by the search terms. A combination of the keywords "*infraestrutura verde*," "green infrastructure," "sanitation" and "*saneamento*" resulted in 28 publications in Scopus and 14 in WoS. By excluding titles repeated in both databases, a total of 34 documents was reached. The characteristics of these documents are presented below.

Table 1 summarizes the search string used in each database.

Table 1

Search string used

DATABASE	SEARCH STRING
SCOPUS	(TITLE-ABS-KEY (“*infraestrutura verde*” OR “green infrastructure”) AND TITLE-ABS-KEY (“sanitation” OR “*saneamento*”))
Web of Science (Core Collection)	“*infraestrutura verde*” OR “green infrastructure” (Topic) AND “sanitation” OR “*saneamento*” (Topic)

Source: Authors

At the same time, a non-systematized search was performed for articles, documents and legislation on GI and basic sanitation. A bibliographical review was carried out on GI concepts, definitions and applications, in both the Brazilian and international context. This was based on scientific articles available in databases such as SciELO and Science Direct; theses and academic works that address the subject; and publications and methodological guides prepared by different institutions, available on corresponding websites. The keywords used in this search were “*infraestrutura verde*” and “green infrastructure.”

Complementarily, a secondary data survey was carried out based on data made available by institutions related to “basic sanitation,” aiming to provide an overview of sanitation and Municipal Sanitation Plans in Brazil. In addition, based on a bibliographical and documentary review, methodological guides and public policies were analyzed by studying the content of legislation related to the subject, seeking to identify the guidelines of the legal and institutional framework regarding its planning and management.

By reading the material obtained in the searches, it was possible to establish a parallel between GI elements and basic sanitation services, resulting in the table in Figure 2. Subsequently, a brief discussion was held on the relationships between sanitation and GI and between GIs and PMSBs, considering the latter as possible inducers for the design and implementation of such strategies.

Results and discussion

Bibliometric analysis

The databases used offer the possibility of checking bibliometric analyses of the results. In this sense, some indicators of interest were selected by crossing data from both in the following figures. The documents resulting from the research may fit into more than one country and one research area.

Figure 1

Selected publications

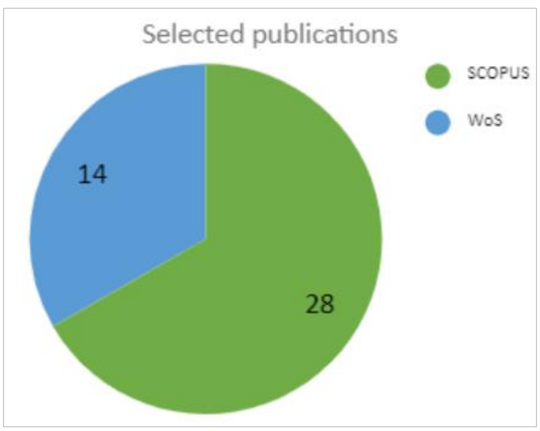


Figure 2

Focus of publications

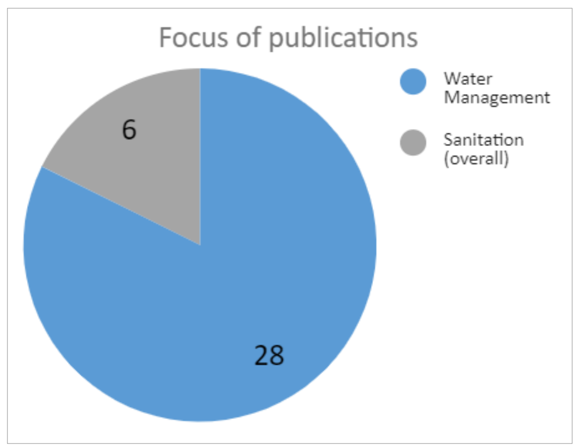


Figure 3

Kinds of publication

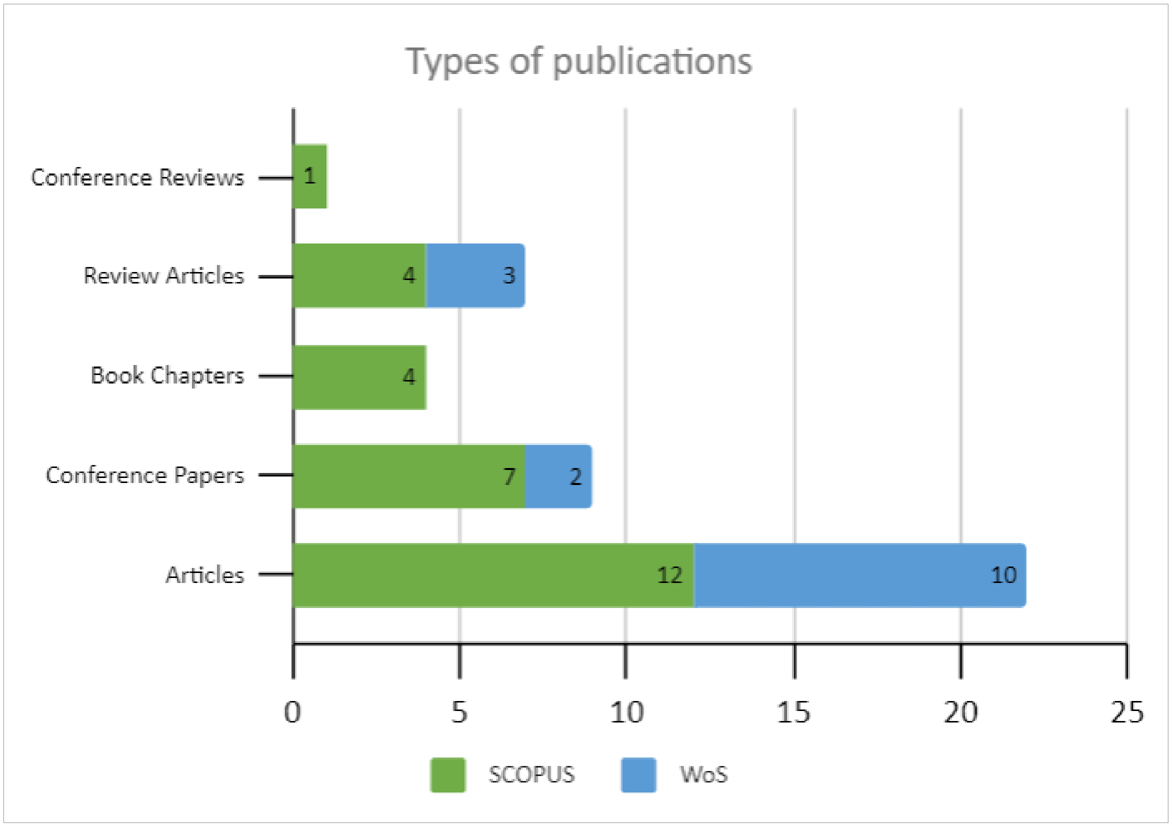


Figure 4

Publications by year

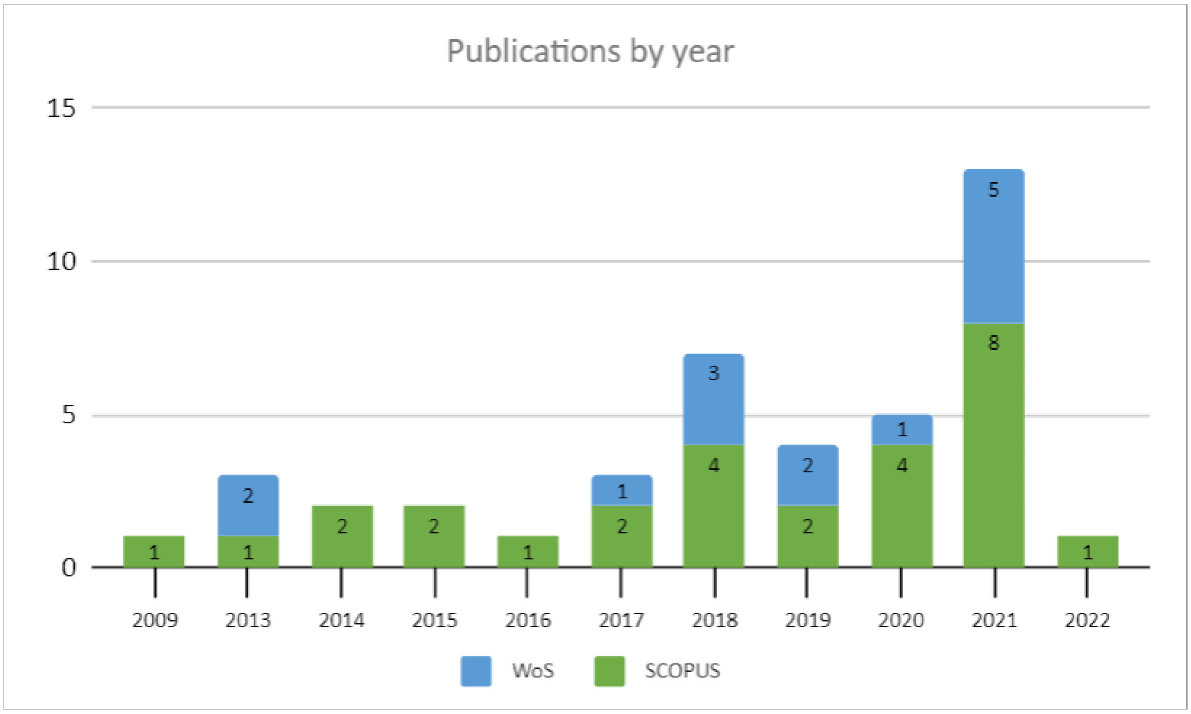


Figure 5

Publications by country

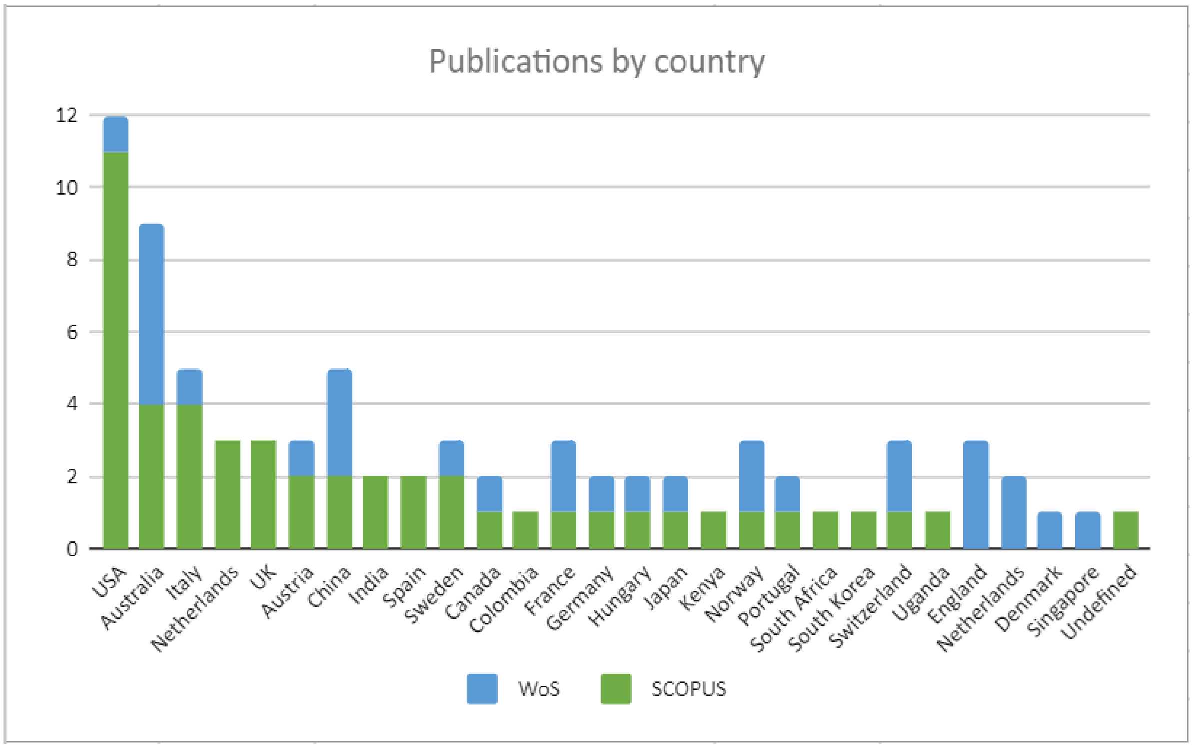
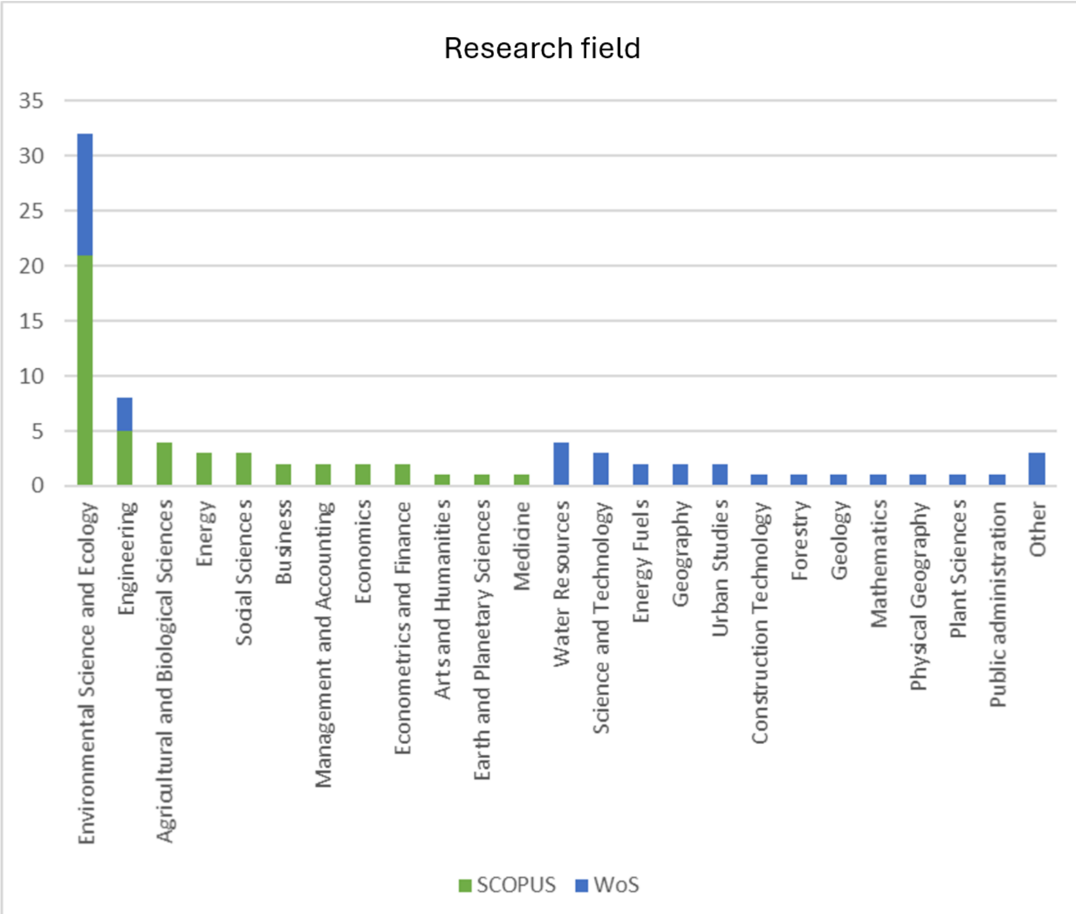


Figure 6

Research field of publications



According to Figures 1 and 2, most of the studies were collected from the Scopus database and the predominant focus is “water management.” Most of the publications are articles (Figure 3) and 2021 is the year with the highest number of publications (13), as opposed to 2009 and 2022, which have the lowest number (one each) (Figure 4).

Case studies were focused in areas in Africa, China, Indonesia, the United States, Italy, India, Spain, Germany, Sweden and Portugal, among others. However, it is noteworthy that the majority are of US origin and, secondly, Australian (Figure 5). Regarding the research field of such studies, Figure 6 shows that most focus on “environmental science and ecology.”

Bett et al. (2022), Douglas (2018) and Thakur and Bhonde (2021) addressed floods in their studies and agree that the use of GI among NBS can contribute to mitigating their occurrence as well as possible resulting negative impacts. Bett et al. (2022) identified three infections deriving from floods. Douglas (2018) pointed to lack of communication, conflict of interests and actions by different actors as some of the challenges to using GIs for such events. Thakur and Bhonde (2021) reported the lack of integrated structural and institutional planning and intervention. Mesgar et al. (2021) presented the negotiation process in a case study involving GI in six informal settlements.

According to Ferreira et al. (2013), the resilience of infrastructures and cities can be improved by integrating more sustainable actions and structures, including the use of GI. Such integration was also discussed in the studies by Tao (2019) and Zischg et al. (2017). Dong et al. (2017) analyzed resilience by focusing on the urban drainage system and comparing GI and gray (conventional) infrastructure.

Among four globally significant initiatives to support a more efficient and sustainable future in water supply, Vörösmarty et al. (2018) addressed watershed banks of GIs, besides discussing the challenges of achieving water security in a sustainable way.

Cheshmehzangi et al. (2021) argued that GI solutions must be accessible to all sectors, communities and people. Their work considers GIs for urban sustainability in underdeveloped areas, as does a study by Prescott et al. (2021), who presented a review of GI projects targeting wastewater. In turn, in a case study, Vollmer and Gret-Regamey (2013) evaluated rivers as municipal infrastructure that meets the need for environmental services (water, sanitation and recreation) of the poorest populations in developing countries.

Li et al. (2017) carried out an assessment of factors that influence the development of urban infrastructure by using statistical models, while Bridgewater (2021) commented on ecohydrology and its influence on the implementation of the SDGs.

Considering the countless GI possibilities (location, dimension and techniques) for each analyzed context, Eaton (2018) aimed to “identify the most effective combinations of different green infrastructure techniques for the study basin,” hoping to contribute to better decisions by managers regarding urban stormwater control. Stormwater is also the focus of the work presented by Shapiro (2016) and Bertrand-Krajewski (2021), who provided an overview of the evolution of integrated urban stormwater management. In turn, McGillis and Fitzgerald (2015) carried out a case study which considered the challenges posed by stormwater management.

Zhou et al. (2009) reviewed documents on sustainability that were published from 2006 to 2008, including sections on GI and supply, sewage and rainwater services. Jamwal et al. (2020) presented “the concept of temporary green infrastructure (TGI) as a typology of speculative innovation […] within highly unpredictable, space-constrained and contaminated river basins.”

Faedda and Plaisant (2021) aimed to outline possible scenarios for integrated water resources management. Nzimakwe (2020) addressed the challenges of water and sanitation services for urban planning and smart cities of the future. Poosti et al. (2020) carried out a feasibility study of GIs as alternatives for using recycled water. ASCE (2019) presented 18 papers selected at the 2019 World Environmental & Water Resources Congress, including subjects such as urban flooding, water and sanitation sustainability, and resilience through GI.

Franco-Torres et al. (2021) discussed urban water paradigms and how GIs fit into the new paradigm. Herslund and Mguni (2019) examined water management practices and discussed possible alignment with a sustainable agenda.

Eger and Stein (2015) presented the initiative that “negotiated the first consent decree in the United States to use the concept of integrated planning” with a focus on watersheds and green infrastructure aiming at water quality. The country also served as the basis for the study by Kertesz et al. (2014) for modeling the “hydrological and economic effectiveness of stormwater utility credit programs for single-family homes.”

Dal Ferro et al. (2021) described an experiment with green walls for treating kitchen gray water. The treatment of wetlands was the focus of the study by Langergraber and Masi (2018) and Ramirez-Rubio et al. (2019) used a “health in all policies” approach to consider the impact of sanitation on urban health.

Martín et al. (2020) described the different solutions and tools used to improve the water quality of a eutrophic lake in Spain. Schuetze (2018) discussed in a chapter the best practices for sustainable urban development in the city of Freiburg. In turn, Hagekhalil et al. (2014) presented GI projects planned for the city of Los Angeles.

Common themes across these documents include the importance, need and urgency of improving water planning and management, including sanitation services; feasibility studies of equipment and structure networks for each evaluated area and context; necessary public policies; sustainability; public health; urban expansion and population growth; resilience and/or adaptability of structures and cities; integrated solutions; multidisciplinarity required to plan and implement green/blue infrastructures; integration of structures and professionals; NBS; environmental and/or ecosystem services; the contribution of GI to poorer or more vulnerable areas and/or developing countries; challenges posed by climate change; events such as floods; and community support and participation in decision-making processes.

Possible relationships between Sanitation and GI

Table 2 lists some GI elements and relates them to basic sanitation services (urban drainage, water supply, solid waste and sewage), revealing possible benefits and/or functions of GIs for each of those services.

Combined, the elements suggested may comprise a GI network, acting in complementary ways to address different sanitation needs, among others, both on a macro planning scale (which could be municipal, state, regional or even national) and on micro project (private or local) scale.

Table 2

Relationship between green infrastructure elements and their potential benefits/functions and sanitation services

Typologies/Elements	Functions/Benefits
Specially protected spaces Green sidewalks; tree-lined streets; greenways; rainwater beds Green walls and green roofs Green floors and flooring	Urban drainage: conservation of vulnerable areas. On-site infiltration and retention of rainwater. Increased stormwater absorption capacity, contributing to reducing surface runoff, floods and inundations. Erosion and siltation control on slopes and water body margins. Supply: expanded water absorption areas and water availability in common and/or specific underground reservoirs for reuse, in addition to protection of surface water sources. Solid waste: possibility of reusing or recycling waste in the construction of structures used in some typologies/elements. Sewage: better filtration and retention of some contaminants present in irregularly discharged sewage, whether intentionally or accidentally.
Urban agriculture	Urban drainage: recovery and use of water in its natural cycle for food production, in addition to contributing to water filtration and minimizing possible floods resulting from highly impermeable areas. Supply: greater water infiltration and recharge of underground reservoirs and/or collection structures for reuse. Solid waste: better disposal and recycling of organic waste transformed into fertilizer. Minimized consumption of materials and production of waste in areas of concentrated production, and reduced food transport from those areas to consumers.

Continued on the next page

	Sewage: possible use for fertigation of certain types of sewage in specific production areas, following analysis and approval by competent bodies.
Detention, infiltration and retention lakes and ponds	Urban drainage: protection and restoration of water quantity and quality by filtering water, managing stormwater and mitigating floods and consequent damages. Supply: contribution to the water cycle in the environment by enabling greater water infiltration and recharge of underground reservoirs and/or collection structures for reuse, in addition to protecting surface water sources. Solid waste: possibility of reusing or recycling waste in the manufacture of structures used in some typologies/elements. Sewage: better filtration and retention of some contaminants present in irregularly discharged sewage, whether intentionally or accidentally.
Evapotranspiration basins, sedimentation, banana circles; natural and/or constructed wetlands; sand/planted filters; macrophyte bed.	
Aquatic/absorption/stormwater/infiltration/filtering/ floating/vertical gardens; rain barrels.	
Bioswales; green gutters; infiltration trenches; green ditches and furrows.	

Source: Authors, based on Benedict and McMahon (2006), Vasconcellos (2015) and Santos & Enokibara (2021).

In addition, the possible relationship between IV typologies and basic sanitation services is discussed below.

Urban drainage and water supply

Many of the possibilities for using GI elements relate directly to urban drainage issues and, indirectly, to water supply, since they include alternatives for harvesting, treating and managing this resource, in addition to its rapid runoff, as used to be the case in the traditional drainage approach (Christofidis et al.; 2019). Because of these relationships, drainage and water supply are discussed here together.

In this sense, it is worth noting that urban development and the consequent increase in impermeable areas during the last decades have increased both the intensity of surface runoff and the amount of pollutants in stormwater, which end up in water bodies (Lucke & Nichols, 2015).

Unlike conventional stormwater management systems, GI relies on the combined use of vegetation and soil, topography and bioengineering systems, and thus plays a role in controlling the amount of accumulated stormwater and surface runoff, contributing to reducing the occurrence of flooding in urban areas.

In addition, GI treats surface runoff before it flows into water bodies, either through infiltration, chemical adsorption or biological processes (Li et al., 2019). Therefore, these waters will reach the water bodies in a cleaner state, requiring less self-purification capacity (Von Sperling, 1996). As water bodies are directly connected to the water collection and treatment system for urban supply, these elements have the potential to help relieve the pressure on sanitation infrastructure.

Additionally, by employing green roofs, rain gardens, bioswales and other elements, GI restores hydrological functions of the landscape and manages water on site through natural processes. From this perspective, GI also revitalizes biodiversity and regenerates ecosystem services such as flood control, water quality improvement and aquifer recharge (Dhakal & Chevalier, 2017).

Although both gray infrastructure and GI have the potential to contribute to the resilience of urban drainage systems, the latter shows greater adaptability and sustainability (Dong et al., 2017).

Moreover, as GI generally uses natural processes of soil and vegetation, it requires considerably fewer manufactured materials than gray infrastructure. Therefore, its use advantageous not only in terms of cost-benefit, but also of the efficient use of the material. (Dhakal & Chevalier, 2017).

Sewage sanitation

The issue of sewage is addressed in a more targeted way towards needs and possibilities related to effluent treatment.

Brazil is far from achieving universal access to sewage collection and treatment. According to Bonzi (2013), this is partly due to the economic unfeasibility of building and operating conventional sewage treatment stations in small cities and isolated communities, as their operation involves high costs with maintenance and specialized labor.

The term “isolated communities” refers to housing centers that, for technical, economic and/or political reasons, are not connected to public basic sanitation services, leading to the adoption of local, single-family or semi-collective solutions. “These can be located in urban, […], rural or coastal outskirts and can even be very close or contiguous to the regions served by municipal sanitation services, yet, even so, be disconnected from them.” This is the case in many slum areas (Tonetti et al., 2018).

Decentralized systems can be defined as those that collect, treat and dispose of (or reuse) wastewater close to where it was generated. When designed, built and operated correctly, they are capable of guaranteeing social, economic, environmental and operational benefits (Tonetti et al., 2018). Prominent among such benefits are: 1. improved health of the local population; 2. landscaping potential; 3. reduced pollution of soil and local water bodies; 4. improved local ecological conditions; 5. reuse of water and nutrients.

In the context of GI, one notes the affinity of decentralized systems with its principles, as they present multifunctionality, integrating the landscape and providing ecosystem services.

Therefore, using GI, which initially helps with sewage services, can also contribute positively to water supply services. That is because, by releasing effluent with better quality parameters into the water source, such water is preserved and will consequently have better characteristics when captured in the supply system, requiring less water treatment.

Another advantage of decentralized treatment systems highlighted by Bonzi (2013) and Tonetti et al. (2018) is the fact that they are generally not rejected by the local population, especially when they participate in the choice. Bonzi (2013) also points out that, in some cases in which they are treated with landscaping, the role of sewage purification is not perceived by the local inhabitants.

Within this context, a decentralized system which is also a GI is the so-called constructed wetland (CW) or root zone, "which is composed of ditches with waterproofed walls and bottom, and can be flooded with sewage to be treated" (TONETTI et al., 2018). CW are engineering systems designed to optimize processes already found within nature and, therefore, are considered environmentally friendly and a sustainable option for wastewater treatment (Dotro et al., 2017). In this sense, this type of system has similar traits to those of the GIs studied here.

Other decentralized alternatives for sewage treatment that are related to GI elements are banana circles and evapotranspiration basins (Tonetti et al. 2018).

Solid waste management

Regarding solid waste, this work did not find clear references in the consulted literature relating GI elements to the solutions applied to this sanitation element. Nevertheless, some considerations can be made.

The first point refers to activities and spaces related to composting, which can be linked to the management of urban gardens, classified among GI elements.

The second point is that one of the benefits of GI, according to Benedict and McMahon (2006), is its ability to promote environmental education and citizenship. This fact, added to the cultural services provided by nature, such as the scientific and educational appreciation of nature and an increased feeling of belonging to a community, may play an important role in the handling and management of solid waste.

The National Policy for Environmental Education, Law 9795/1999, provides that “society as a whole should be permanently attentive to the development of values, attitudes and skills that encourage individual and collective action aimed at the prevention, identification and resolution of environmental problems” (Brasil, 1999). Therefore, society must be included in addressing the problem and solution of final disposal as well as in managing solid waste. In this sense, one of the potentials of green infrastructures is the greater integration of the population with such needs.

The association of GI with basic sanitation needs increases the potential for prevention, non-generation and even reduction of waste that might otherwise be unduly disposed of in green areas when there is no feeling of belonging and citizenship in the relationship with these urban spaces. This perspective is in accordance with the National Policy for Solid Waste (PNRS), which, among its goals, provides in Article 7 the “non-generation, reduction, reuse, recycling and treatment of solid waste, as well as environmentally friendly and proper final waste disposal” (Brasil, 2010).

GIs and PMSBs

The connections between elements of green infrastructure and sanitation services having been made, and considering the PMSB as a mandatory planning instrument for all Brazilian municipalities, affording greater access to federal funding, it can be highlighted that, especially from the perspective of multiscalarity and multifunctionality, such plans have the potential to include GI elements in municipal planning in a strategic way. According to the European Commission (European Commission, 2014), in order be properly planned and have the potential to be actually implemented, a GI must be incorporated into public policy. One of the ways to do this is through PMSBs.

It is worth stressing that municipalities equipped with a Municipal Master Plan have the opportunity to align their PMSB with said plan. It is paramount to set guidelines for land use and occupation not only by considering the needs, distribution and density of the population, but also by using new paradigms that include GI approaches. Relating land use and occupation, based on innovative principles and considering the support capacity of natural and constructed systems, is essential for the design of good a PMSB.

In turn, when incorporated into public policies, especially PMSBs, since, as shown in Figure 2, there are several opportunities for this, GIs can be considered and provided in programs and projects of short, medium and long term. There is also the possibility of obtaining funds, which significantly increases the chances of implementing GI elements at municipal level (Brasil, 2011; FUNASA, 2012; CNM, 2014).

Furthermore, the PMSB, by providing alternative approaches to traditional solutions to different sanitation issues, especially sustainable urban drainage and decentralized sewage treatment, as argued by Singapore (2011) and Tonetti et al. (2018), presents a potential direct relationship with the use of GI elements in municipal public planning and management, promoting greater opportunities to resolve sanitation issues with lower financial and environmental costs. It is also worth highlighting that PMSBs should consider both urban and rural areas, where alternative solutions and green infrastructure elements have great potential for implementation, thus contributing to true universalization rather than just focusing on access to networks.

Another relevant aspect of providing green infrastructure elements in the PMSB is the incentive to carry out projects with a low environmental impact, especially at a time when proposals for flexibility in environmental licensing and impact assessment processes are being discussed in Brazil, also affecting the basic sanitation sector (Santos, 2021).

Conclusion

This study corroborates the premise of synergy and relationship between GI elements and basic sanitation services. As they are capable of operating in an integrated manner, these different elements have great potential to fulfill multiple functions, such as when related to solutions linked to the management of urban drainage, water supply, sanitary sewage and solid waste. In addition, they offer various benefits, such as the provision of other environmental services.

GIs have striking characteristics that make them interesting for different realities in the pursuit of countless goals, including greater opportunities for sanitation and more sustainable development.

However, proposing the use of these solutions requires having public policies that guide, encourage and enable changes in traditional conceptions (with greater environmental exploitation). Thus, a more harmonious and technically safe management will be possible when designing and managing human occupation with the lowest possible environmental impact.

This highlights the importance of inserting GIs in the context of public policy so that they have real potential for implementation. And in the absence of specific legislation on GIs, PMSBs have the potential to stimulate and support the planning, implementation and multiplication of GIs by municipalities/regions, thus contributing to the improvement of basic sanitation conditions in different Brazilian realities. Furthermore, the inclusion of GI in the PMSB increases funding prospects.

It is believed that this work can support managers and decision makers in planning and executing strategies and structures to meet needs related to sanitation in Brazilian cities.

Despite the strong relationship between solid waste management and other basic sanitation services, little was identified in the literature relating GI to solid waste. Therefore, new research in this field is suggested.

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