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Review

A Review of the Application of Blue–Green Infrastructure (BGI) as an Effective Urban Flood Mitigation Strategy for Livable and Healthy Cities in Australia

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Abstract: Blue–green infrastructure (BGI) has become a practical approach with emerging attention to addressing flood mitigation in many countries worldwide. The environmentally sound, sustainable approach of BGI has led it to gain scientific interest above other available mitigation techniques, such as grey infrastructure, soakaways, etc. This study was intended to conduct a thorough scoping review, followed by a bibliometric analysis, using the VOSViewer version 1.6.19, of the available flood mitigation techniques and the emergence and effectiveness of BGI as a strategy. The scoping review was based on 50+ recent (between 2013 and 2022) journal research papers. The study enabled the development of an elaborative idea about BGI and its applications in Australia, and it describes the trend of research to use BGI for flood mitigation. Following a comprehensive survey, it was established that BGI had been recognized as an effective measure in addressing unexpected floods, and it is indeed a beneficial project in the long term. It mitigates urban flooding, improves the environmental quality by purifying the urban atmosphere, and, further, includes the health and well-being of the community as co-benefits. However, although BGI has many environmental and other connected benefits, there are some restrictions that are decelerating the initiation of BGI as a project. Therefore, this application takes time and effort even before implementation. The bibliometric analysis of this study revealed that robust connectivity is seen in the global perspective between BGI, green infrastructure, and flood risk management, depicting a strong bond. In contrast, in the Australian context, an explicitly networked BGI specifically had yet to be seen, and only "green infrastructure" was used instead. However, the emergence of BGI for flood mitigation was recognized in 2015, while Australian research was likely initiated in 2016. There is less acceleration in Australian studies compared to the global scenario. BGI is a trending topic in scientific research, offering a vast variety of benefits to the country. Concluding, this study strongly suggests an immediate initiation of proper awareness and the development of relatable policies as two primary considerations to encourage the implementation of BGI, which is an effective strategy to address floods in Australia and create livable and healthy cities.

Keywords: BGI; blue–green infrastructure; flood mitigation; urban flooding; climate change mitigation

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1. Introduction

Unprecedented floods occurring in Australia have led to many effects on the community for the past few years. These effects are not just what we can see in the picture itself, but they are just the tip of an iceberg, while numerous indirect effects are being hidden until their effects become visible to the naked human eye [1]. Climate change is currently visible in Australia. Climate change, supported by ill-monitored anthropogenic activities, has accelerated the patterns of flooding, which has resulted in an inability to forecast [2,3]. Although cyclone frequency has decreased during past decades, it is predicted that the magnitude and frequency of flooding will be intensified by climate change, causing severe future floods [4]. Climate change-driven weather extremes like floods and droughts are foreseeable impacts of human–environment coupled systems [5]. Therefore, in determining either to adapt to the effects of climate change or to reduce the impacts of climate change, blue–green infrastructure (BGI) is one of the sustainable strategies that is accessible to increase resilience against the expected severe climate change effects [1].

This review is expected to enhance the knowledge and available BGI strategies applied for flood mitigation. Moreover, it lays an analysis of how effectively urban flood mitigation has gained assistance from BGI around the globe. A research area's state-of-the-art analysis is vital during a literature review [6]. Hence, this paper followed a bibliometric analysis to develop the recent status of the applicability of BGI as an effective mode of addressing urban flood risk in the world. The current applications and scientific research in this area have been gaining an uplifting interest. However, the number of real-world publications and applications is recognized to be low even with supporting scientific research [7].

The current authors develop an extensive literature background on the effectiveness and suitability of this strategy as a flood-mitigating technique and, consequently, elaborate on the factors that may have decelerated its in situ applications. Therefore, the bibliometric analysis, followed by this elaborative scientific background on the research area, develops the current research trends and hotspots for using BGI for urban flood management in global and Australian contexts.

2. Problem Statement

The identified research gap for this study was the need for visible incorporation of BGI in flood mitigation, especially in Australia. This research is therefore mainly focused on the capacity of BGI as an effective strategy or technology in addressing unprecedented climate change-driven flood mitigation. Consequently, it aimed to review all recent and available scientific articles on BGI and flood mitigation. Even though there has been a trend regarding this question, the applicability of it was nearly invisible in the actual context. Hence, this study analyzes the current global technology developments on BGI to set a well-defined picture of the growth of research interest over the past decade. By making researchers aware of the background of this research field, the public will be encouraged to be mindful of the background and encouraged to adapt to this technology more and pursue the long-term benefits extracted through its use.

3. Methodology

The methodology of this research is a systematic review followed by a scoping review covering a systematic literature review on urban flood mitigation and BGI. A scoping review is a research tool that researchers have used to present a broader illustration and an indication of the research area based on the available published research outputs. A systematic review is an evidence-based research tool to analyze available studies. It can be used to develop the existing distribution of knowledge worldwide [7].

For this literature review, the Web of Science, Scopus, and Science Direct databases and other peer-reviewed international journal articles from the recent past decade (2013–2022) were used. In analyzing the articles, the authors followed the stages depicted in Figure 1. The main keywords used to identify relevant literature were "Blue-Green infrastructure", "flood mitigation", and "Australia".

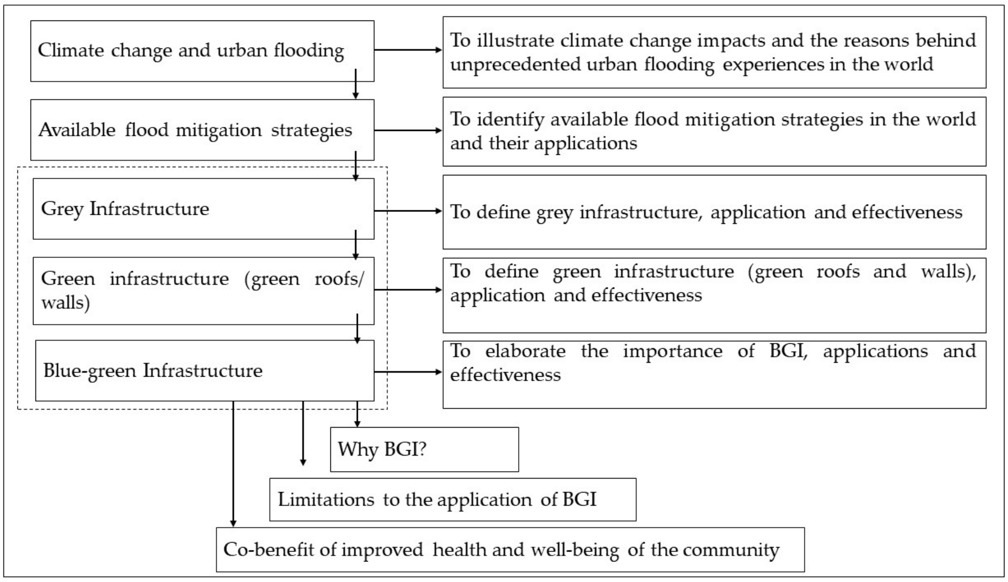

Figure 1. Stages of the systematic literature review on BGI.

The main focus was on the BGI strategy as a worldwide flood mitigation technique with an emerging scientific interest. A thorough analysis was conducted to assess these three techniques i.e. grey infrastructure, green infrastructure and BGI and evaluate their effectiveness individually in real cases, as depicted in the literature.

An extensive literature survey on BGI as an innovative theory in flood mitigation was followed by a bibliographic analysis, as shown in Figure 2, to recognize the availability and applicability of published journal articles. In a bibliometric analysis, a quantitative analysis is conducted and statistics are used to explore the research development and available knowledge structure of the specific field of study. For this study, VOSViewer software version 1.6.19 was used for the bibliometric analysis as a tool for developing an exploration map or a visualization based on the bibliometric network data. It presents an output as a cluster map. In this study, the authors expected to examine the co-occurrence of keywords related to the research area. In these co-occurrence maps, the size of the cluster nodes and the thickness of each link denote a comparative strength of the links and keywords [6].

Keywords for the analysis were selected based on the extent of their relevance to the suggested area of research. To acquire databases of research publications, citation databases, namely, Web of Science, Scopus, and Science Direct, were used. The publication keywords were analyzed to see the emergence of the concept of BGI as a flood mitigation tool over the past ten years (2013–2022). After defining the keywords and obtaining the databases, the analysis was conducted using VosViewer software version 1.6.19.

For the bibliometric analysis, the Web of Science, Scopus, and ScienceDirect databases were used, followed by a pair of keyword combinations that was selected to define the variations in publications around the globe and specifically in Australia during the recent past decade (2013–2022). The selection of below-mentioned keyword variations was conducted by matching the scoping literature review and the study objectives. In this study, the authors expected to recognize recently published scientific articles during the past decade. During the scoping review, it was identified that the keywords below had been frequently used together. Therefore, after thoroughly analyzing the keywords, the sets of variations below were considered to analyze the bibliometric data available worldwide. These keywords were collectively used as a single phrase by allowing the databases to filter more matching articles for the study and to limit the papers deviating from the standard scope and objective of the study. The authors primarily intended to consider scientific papers that were directly related to the scope, and the reason why these keywords were not replaced by any other was to maximize the engagement of publications to this review.

Concerning the area of research, the following variation types were considered:

- Variation type 1: "Blue-Green infrastructure" + "flood"
- Variation type 2: "Blue-Green infrastructure" + "flood" + "Australia"

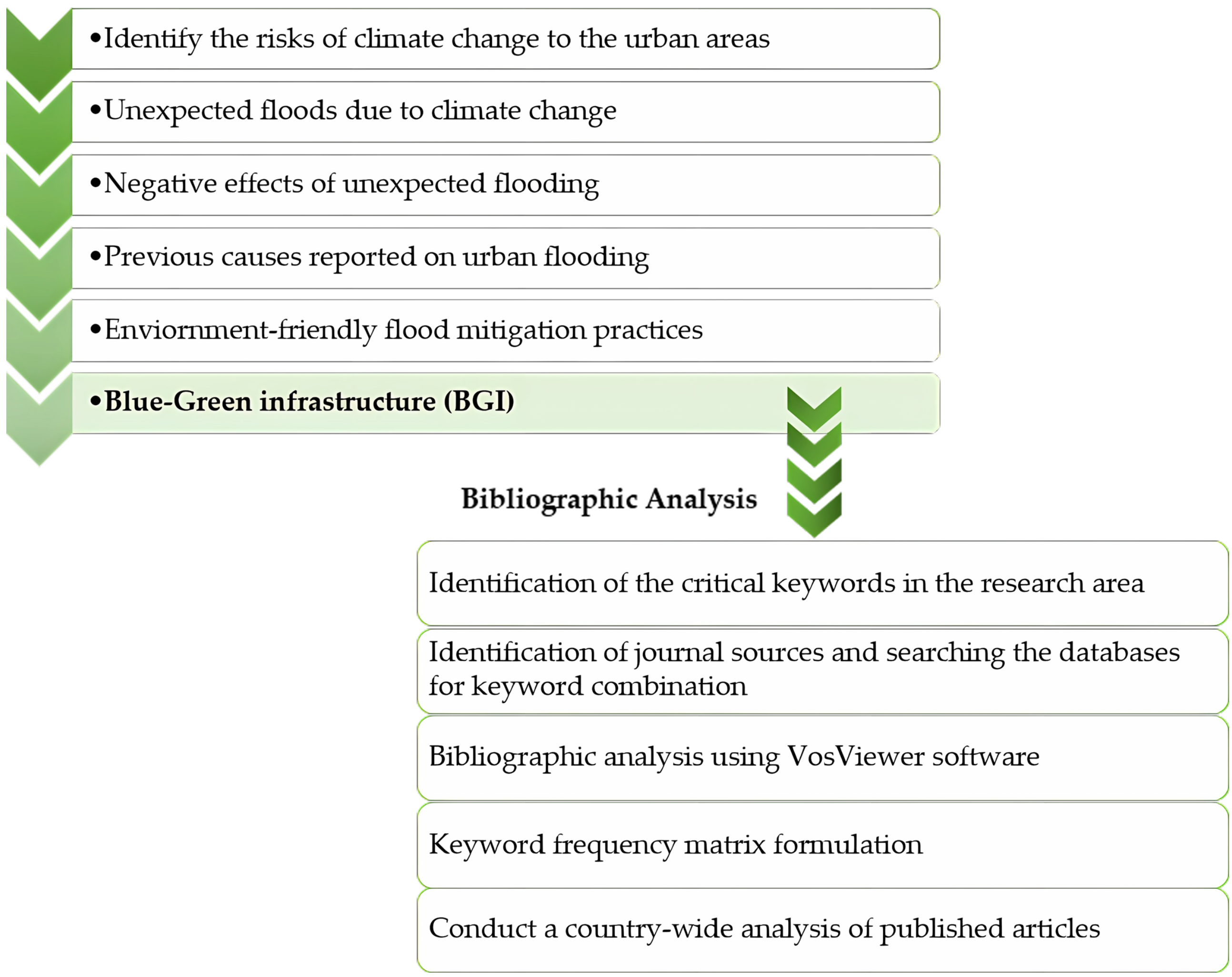

Figure 2. Methodology of the study: systematic literature review followed by a bibliometric analysis.

Table 1 and Figures 3 and 4 below illustrate the distribution and frequency of journal articles published on BGI as a flood mitigation strategy during the past decade (2013–2022). They define that variation one bears more published journals, while variation two is limited.

Table 1. Distribution of journal articles published between 2013 and 2022.

Web of Science	**2022**	**2021**	**2020**	**2019**	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**
Variation 1:	9	9	7	7	3	1	2	0	0	0
Variation 2:	2	1	0	0	0	0	2	0	0	0
Scopus	**2022**	**2021**	**2020**	**2019**	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**
Variation 1:	26	13	6	0	0	0	0	0	0	0
Variation 2:	1	0	2	0	0	0	1	0	0	0
ScienceDirect	**2022**	**2021**	**2020**	**2019**	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**
Variation 1:	53	50	25	19	10	7	6	2	0	0
Variation 2:	20	19	11	7	4	2	2	0	0	0

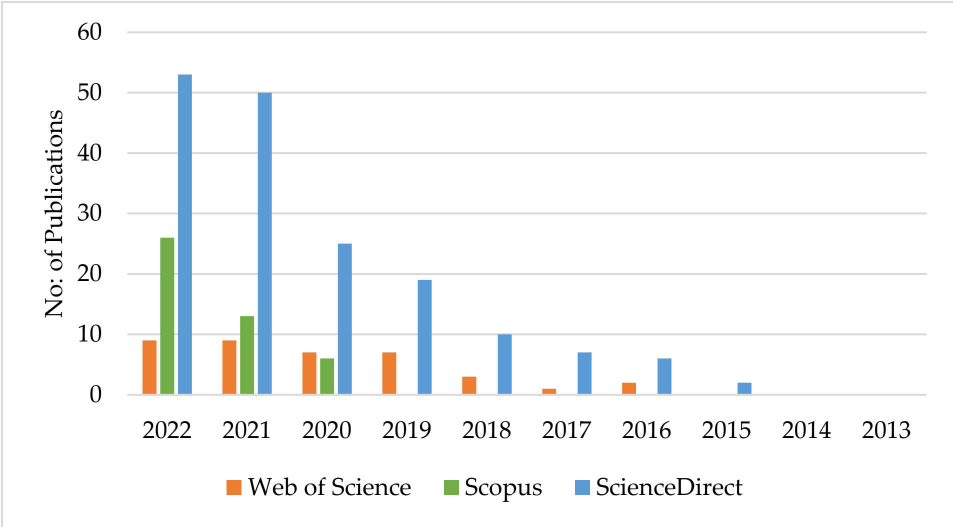

Figure 3. Frequency of publications for variation 1.

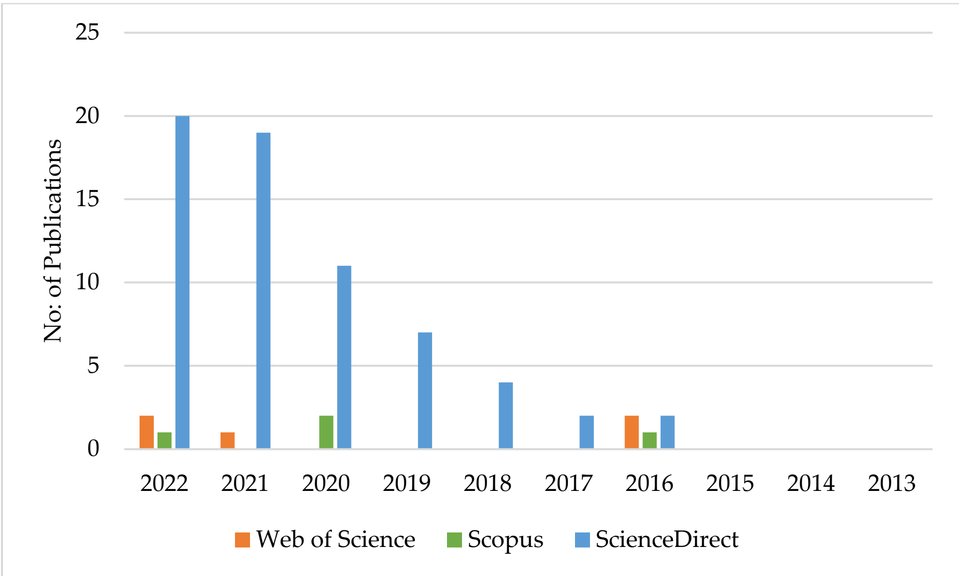

Figure 4. Frequency of publications for variation 2.

4. Literature Review: A Mixed Approach

This study presents a literature review conducted with a mixed approach of systematic and scoping review. It therefore offers scientific conclusions available in the world in a broader perspective and also an analysis of how the research in the subject area has been developed during the past decade.

4.1. Scoping Review

4.1.1. Key Drivers/Causes of Urban Flooding

The rapid growth of urbanization leads to direct and indirect effects on the human world. These effects were seen to cause negative impacts on social, environmental, and economic development in countries [8]. The imbalance of the environment has caused many environmental changes, such as atmospheric temperature changes, ozone depletion, unpredictable precipitation patterns, etc. [9]. For instance, some European, Asian, and African countries face climate change effects with long periods of extreme droughts and intense rainfalls [10–12]. Improved quality of life standards in the present society are now crucially considerable. Human needs have become more complicated than in previous decades. For example, in the past era before the 1990s, shelters were one of the basic requirements of human lives, and they were used mainly to protect people from harmful weather conditions and to gain privacy. However, today, shelters have become more complex based on perceptions of designing buildings and the people [6]. Urbanization and industrialization affect the expected behavior of the environment [13]. Hence, these developments affect the natural proceedings of the domain in more than one way. For example, the trend of high-rise buildings in highly dense urban areas has formed a barrier to the natural wind flow, which ultimately depreciates the atmospheric quality of the site. Another important aspect is that such constructions of buildings in urban areas reduce the water infiltration capacity, which presents the risk of flooding, which is the most challenging environmental hazard in the current world [10,14].

Urban flooding is considered a critical global challenge in the twenty-first (21st) century, followed by the risk of future floods that are exacerbated by urbanization, climate change, and aging infrastructure [15]. A total of 68% of the world's population is now predicted to live in cities [14], which will eventually elevate the flood risk for people, the infrastructure, and property and will increase the pressure on already overburdened and inefficient drainage systems and water management systems by 2050 [15]. Thus, recognizing and addressing this critical hazard has become more vital than before.

4.1.2. Urban Flooding and Its Effects

Incidents such as these have resulted in urban planners developing more efficient grey infrastructure, which means gutters, drains, and retention basin-like components to be built to re-establish the ground's stormwater flow capacity and enhance the area's water-holding capacity [15]. Changes in the weather conditions, such as intense precipitation due to climate change, naturally impact a broader range. These unpredictable heavy rainfalls have caused severe floods in many countries recently, where major disruptions in human lives, infrastructure, supply chains, health, and safety have been caused, even including the country's economy [10]. Flash floods were recorded to affect the agriculture sector more critically by damaging the economy of agribusinesses through the disruption of vegetation, technologies, and farm animals. The increased frequency of flash floods has greatly threatened public safety, socioeconomic activities, and properties. Even though rainwater is a freshwater resource, it can be identified as a cause for hazards under several conditions [13,16]. As unexpected heavy precipitation patterns can build the risk of extreme flooding when emergency preparations are absent, concurrently, freshwater bodies available for human use are at risk of being polluted due to contaminated flooded water, causing severe health issues in people [6]. Natural wetlands and other water bodies act as a shield against environmental pollution and are also one of the main parts of the natural cycle. Reduction in the land area for these biological processes generally has many adverse effects. [17,18].

For instance, Australia faced extremely hazardous flooding events in 2022 as a result of the weather pattern that was influenced by "ex-Tiffany" in the north and west of South Australia (Figure 5). Another flood event was witnessed in South East Queensland due to a low-pressure system over Queensland's southern coast which led to moisture being dragged from the Coral Sea in the north. Moreover, in February (22 February to 7 March), a major flood occurred resulting from intense rainfall in several areas, including Brisbane, Maryborough, the Gold Coast, etc., caused flash flooding and riverine flooding (Figure 6). The flooding event experienced in 2022 cost thirteen lives, including six people from the Northern Rivers area, four people from Sydney, and one from Central Coast, Broken Hill, and Grafton. Other than that, 21,170 properties were impacted, 8108 were inundated, 10,849 were damaged, and 4055 were assessed as inhabitable (Figures 4 and 7) [19].

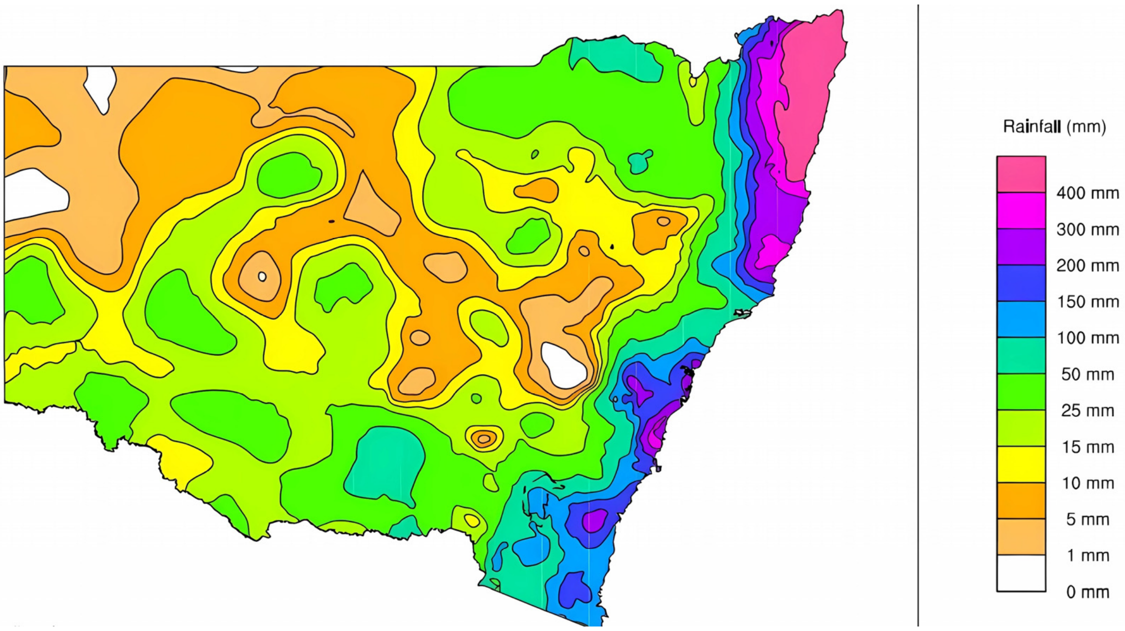

Figure 5. Australian Rainfall Analysis (mm) (week ending 2 March 2022) (http://www.bom.gov.au accessed date: 21 January 2023) [20].

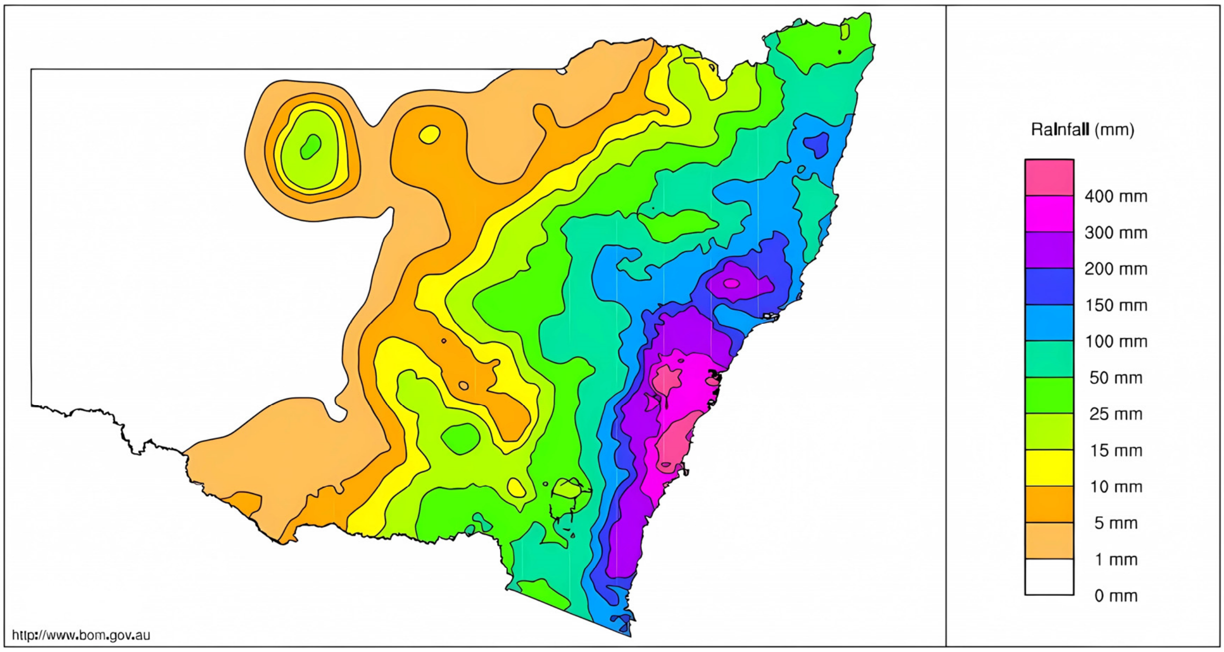

Figure 6. Australian Rainfall Analysis (mm) (week ending 9 March 2022) (http://www.bom.gov.au accessed date: 21 January 2023) [20].

These damages were recorded as some of the highest numbers resulting from a natural disaster in recent history. The most vital factor related to these incidents was the unprecedented catastrophe. These floods resulted from linked La Niña events, climate change effects, and unsustainable constructions. In Victoria, Australia, short-term rain bursts have become more intense and frequent [19]. It has been established by many scientists that these unprecedented rain bursts have resulted from climate change effects. It was estimated that around a 14% increase can be seen in the frequency of short-term, intense rain bursts in Victoria, Australia. The global temperature increase due to climate change has facilitated these rains by capturing more water than cold air [21].

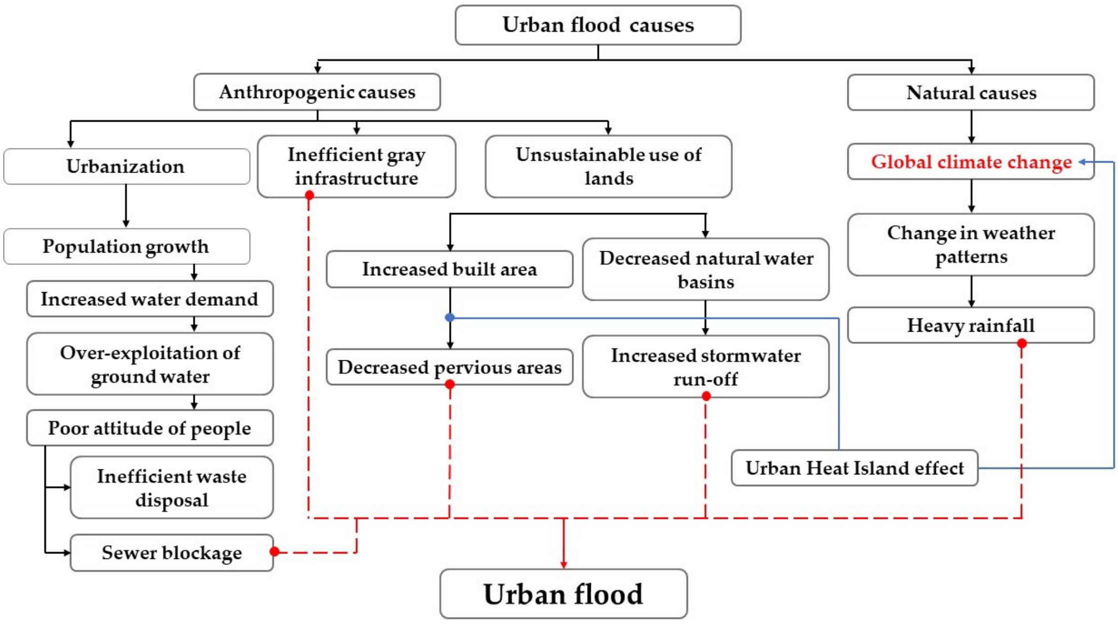

Figure 7. Origins of unprecedented urban floods.

4.1.3. Mitigation Strategies

The concept of flood-resilient cities has gained attention from researchers in past years. They suggest mitigating flooding at the source by expanding the stormwater retention capacity, which matches the generation [22].

Gray Infrastructure

Temperature changes associated with the heat island effect, carbon and other greenhouse gas emissions, noise pollution [23], water pollution, and depletion of the biodiversity in urban cities are the impacts that primarily concern researchers. Many implementations are being performed to mitigate and take control of these environmental impacts, and further developments of such technologies are underway [24]. Many innovative ideas are more related to environmental sustainability coupled with eco-engineering from grey to green; the efficiency of eco-engineering is the critical point during this decade. Green systems have arisen due to their presence and importance worldwide [25].

As a result of modern architectural building designs and urban landscapes, there is a tendency to convert most of the rainwater into stormwater runoff. This is where grey infrastructure applies and safeguards this storm runoff adequately. Networks of pipes, drains, and many methods in grey infrastructure facilitate drainage. However, conventional drainage systems with lines are currently being tested as a disturbance to nature, leading to pluvial flooding [17]. A combination of sustainability and proper mapping is expected to move this grey infrastructure toward increasing efficiency and diminishing the occurrence of flash floods in urban areas [26].

Other than the application of mitigation strategies, adaptation is also of importance. To adapt to such effects, proactive changes should be taken in the current area, and further mitigation plans are required.

Stormwater drainage systems serve as a necessity for the protection of people and infrastructure from sudden pluvial floods. Existing infiltration pits and pipe channels have a limited capacity for a sudden water load [27,28]. Small- to medium-sized networks of treatment facilities, pipelines, and pumping stations comprise the wastewater recycling constellation. Therefore, these facilities clean sewage to a high standard by allowing a supply of it for non-potable uses [8]. Moreover, centralized pumping and pipeline networks were implemented in the early 1890s in Melbourne, Australia. Its sewage system had expanded facilities of treatment to cover the required demand [8]. Consequently, conventional integrated piped-drainage-system-based stormwater management methods have become a core point of criticism for being unsustainable [29].

Since then, sustainable practices have rapidly been approaching countries such as Australia, New Zealand, and Europe. Today, they have already initiated planning and applied them to cut down on negative impacts in the future. Therefore, significant changes have been made in planning urban grey infrastructure systems during the past few decades [30]. Factors such as determining the soil characteristics in wetlands and forests were used to identify their capability of groundwater retention and absorption [31]. The two primary considerations of designing a drainage system are that it should have a considerable water capacity during a heavy rain incident and pass the contents effectively and quickly from cities. To achieve these two components collectively, environmentally friendly technologies should be used from the beginning of the designing stage. Previous research has proven evidence for the main problems current cities have faced with their existing stormwater and drainage systems. Most cities have used small-diameter pipes, which are now considered inappropriate due to their low capacity for collecting water during a short period [31].

BGI

In adopting green strategies to ease an environmental burden, green roofs offer a wide range of benefits, including thermal insulation, aesthetic appearance, wildlife restoration, carbon dioxide sequestration, etc. Moreover, they play a significant role in flood mitigation, mainly in urban contexts, by retaining rainwater in their layers to a certain extent [32]. Therefore, only the additional water content that exceeds the green roof's capacity passes to the local sewer system through pipes. The innovative technologies recently implemented consist of the capability to capture an increased volume of rainwater and reuse it, retaining it in watersheds [33]. Urban water management and sewerage systems will reduce ecological damage to the natural habitat [25]. Urban designs need to be critically focused on climate change and the loss of biodiversity to obtain the maximum use of the ecosystems. Sustainable practices should be used in urban environments [13].

Reducing the impact of the development of natural hydrological systems related to water flow and quality has been importantly considered in recent research [13]. Mainly, hydraulic models have been focused on urban flooding control, and sustainable stormwater management has been suggested as an alternative [17,25]. The public was eager to raise the standard of water bodies and the environment with available knowledge and awareness of environmental conservation [9]. Blue–green infrastructure (BGI) is one of the sound approaches that has recently been recognized to address flood mitigation via a sustainable engineering solution. By fusing infrastructure with nature, BGI reduces environmental concerns while employing stormwater management technologies [34]. Bioswales, green roofs, rainwater harvesting systems, and other structures provide significant economic, social, and environmental benefits [6].

Why BGI?

BGI is a comparatively modern phrase that connects the idea of water to green infrastructure and provides practical solutions with several advantages [26,35]. By re-establishing the hydrological volume of the urban environment and regulating stormwater, BGI creates an organized network of semi-characteristic and shared places that use cycles to enhance water quality and oversee water quantity [36]. It is an environmentally friendly innovation, and it has benefited the world by reducing the cost of grey infrastructure and water treatment costs by improving air quality and groundwater replenishment [15]. Sorption and biosorption increase the groundwater's capacity and quality, absorbing heavy metals from polluted water [28]. It supports the processes of natural cycles and many more [37,38].

Furthermore, BGI presents social benefits such as increased physical activity and health levels; improved quality of neighborhoods, air, space, and water; and the ability to withstand climatic change [39]. During the last decade, urban development has shifted with the conceptual methodology of applying BGI in engineering and architecture [11]. BGI contains greenways, parks, natural preserves, lagoons, rivers, streams, lakes, open-air green reservoirs, bio-retention basins, green roofs, rain gardens, and wetlands [14,40–42]. BGI innovations can restore ecosystems. Peak runoff can be reduced to pre-organization levels using a combination of green roofs and bio-retention technologies [35]. Implementing rain gardens, permeable pavements, and green roofs can benefit the environment in numerous ways, such as through groundwater recharge [13]. BGI studies have increased during the last few years; 21 parallel technical papers and 23 research papers have been published in the previous decade. The studies mix aspects and new innovative ideas with engineering, policies, and bio-retention systems [43]. The highest number of sustainable BGI research and publications was recorded in the year 2020. Engineering science covered a lower percentage of the research, at nearly 7.7% [6].

Related to the multiple benefits of BGI, many countries have been concerned about these environmentally friendly implementations [6]. The United Kingdom (UK), Australia, the Netherlands, and Sweden are countries that accepted BGI as a strategy for urban flood mitigation [18]. Moreover, concepts such as Water-Sensitive Urban Design (WSUD) in Australia, Sustainable Urban Drainage Systems (SUDSs) in the UK, and sponge cities in China have drawn attention as adaptation and mitigation techniques that improve the livability and resilience of cities to unprecedented floods [13].

BGI is a concept of the green network, and it is recognized internationally for managing the challenge of urbanization [18]. Investing in this is more effective, with cost benefits [23]. Several societal, ecological, and technological factors affect the many BGI services [44]. A mitigation plan for flash floods and hazard identification studies should be carried out with the knowledge of hydrological engineering. Atmospheric conditions like hot and humid annual precipitation events must be recorded, and data should be accepted to make changes and innovations in the BGI process. For example, a one-hour storm occurs every two years in Singapore and New York City. It makes these regions extremely vulnerable to flood dangers.

Governors and officials in most countries are assessing the possibilities of BGI implementation [26]. Therefore, they should identify the interaction of the soft and hard elements for BGI with the existing land use, which will help to make an excellent symbiotic relationship between the region and the city [18]. In implementing the BGI process, a wetland is one of the significant vital concerns. Artificially constructed wetlands can be used with suitable architectural and green building modules. Agricultural plants such as canna and heliconia have some pollutant-removal efficiencies and better growth in wastewater. Reeds, vetiver grass, and slimmer crops can be planted inside selected places in wetlands [45]. Moreover, without sacrificing the quality and productivity of rice crops, a wetland-filtering system for domestic wastewater might successfully lower phosphorus and nitrogen levels to fulfill Thai water requirements [46]. Other benefits of BGI are cost-effectiveness compared to the grey infrastructure, which is a highly appreciated factor [38].

Despite conflicting findings, controlled urban water systems have generally relied on engineering solutions which frequently involve pipe-based techniques and monofunctional infrastructure [47].

Accordingly, BGI solves numerous concurrent concerns, such as reducing urban runoff and enhancing penetration through pervious surfaces, improving water quality, and restoring aquatic biodiversity [48,49]. When BGI-related wetlands were tested for absorption of nutrients, Putrajaya's built wetlands had a satisfactory nutrient removal performance, which was up to 82% for total nitrogen (TN) and 83% for total phosphorous (TP), which was supported by laboratory investigations [50]. They drew attention to the wetlands' decreased performance during heavy rainfall. Evapotranspiration contributed to the rise in nutrient content. Native plants were suitable for use as wetland crops due to their high effectiveness [15].

The Co-Benefits of Improved Health and Well-Being of the Community

The emerging popularity of BGI is fundamentally based on its efficient multifunctionality and the supply of various co-benefits [23]. Another appealing benefit of BGI is recognizing the diminishing ability and the rampant negative impacts of grey infrastructure. It is undeniable that unexpected flooding causes massive damage to human lives and health. In addressing the core issue of flood mitigation, human lives will be protected through efficient mitigating capacity [51]. In addition, this will reduce harmful diseases being spread among the community, a critical post-flood effect humans face. Apart from BGI's natural ability to improve the health and well-being of the community in the context of a flooding event, it also primarily enhances the aesthetic appearance of the view. Ecosystems set on BGI are visually appealing; this green appearance improves mental and physical health by purifying the urban atmosphere [44].

This significance can be illustrated based on the world's experiences during the COVID-19 pandemic. Since people were locked down in the built environment, it encouraged a critical need for access to blue and green spaces for stable mental health. Therefore, the views of BGI secure mental health while the BGI purifies the urban atmosphere, which is filled with toxic gasses and contaminants throughout its ecosystems [52]. Improved air quality is one benefit that can be achieved, mainly during the photosynthesis processes of green plants [53]. Hence, it is essential to note that while BGI can efficiently assist in flood mitigation as one crucial application, it addresses health issues and improves the community's quality of life. This states that BGI provides environmentally and socially recognizable benefits throughout its lifecycle. It further replicates the highest ability of BGI in addressing climate change impacts and protecting the environment, people, and infrastructures [54].

A survey conducted during the final stage of the COVID-19 pandemic by Dushkova et al., 2021, revealed that people who live in cities tend to appreciate blue and green sceneries and spaces more to improve their mental health and well-being. Even though they do not necessarily know that their mental health is being improved, they love using these BGI concepts to feel relaxed and peaceful. These results critically compel that, in urban areas, the accessibility to BGI is of utmost importance for human health [54].

Current Problems in the Application of BGI

Governmental regulating bodies in most countries have now focused on sustainable development strategies with innovations in addressing climate change effects. Uplifting the quality of life with the slightest environmental disturbance has been the primary concern nowadays. Implementation of these new ideas of BGI will lead to a rise of some gaps, including a need for more tools, abilities, and technical skills.

However, this technology requires a certain level of scientific knowledge, which will then be limited to experts in the related field. The public and students in the country require governmental support and assistance in developing skills and research and development [55]. Furthermore, a lack of knowledge about implementation or efficacy, physical space constraints, and poor and compartmentalized governance are other obstacles to the deployment of BGI [56].

Moreover, more mechanisms and indicators are needed to make it easier to implement policies on time [55]. Even though BGI has been implemented in many countries, it is notable that this technique's adoption rate could be faster. One of the significant gaps identified is institutional barriers, which demonstrate a lack of attention. To elaborate on this aspect, among many assessments in numerous countries, one assessment is a project conducted across seven cities by the European Commission's Horizon 2020. Researchers found that some intra-organizational processes and technical skills impacted BGI implementation [57]. This suggests that the support needed for this technology's implementation by the government is of utmost importance. Therefore, on the one hand, this strategy is an effective and beneficial one in the long term, while on the other hand, it needs support from the authorities for its implementation to emerge rather than being executed by individuals on a small scale. This study critically points out the importance of assisting and tackling intra-organizational processes until the community is widely attracted to this technology [56].

As an overview, specific problems identified in the implementation of BGI for flood mitigation in the world include a lack of capacity, expertise, and knowledge; budgetary constraints; poor governance; a lack of baseline data; the perception of poor services; a shortage of space; and competition with other land uses. There needs to be more awareness of BGI, and there is a need for relevant valuation data [58]. However, this study suggests that all these problems could be addressed collectively by encouraging and developing scientific research further and helping researchers to embrace the community by spreading knowledge and awareness.

4.2. Bibliometric Analysis

Table 2 replicates a colored document frequency matrix of journal article publications with the identified keyword variations in this research area. During the stipulated time (2013–2022), it is seen that the emergence of the research interest in using BGI as a flood mitigation strategy began in 2015. However, there was a gradual increase in publications until 2018 in both variations and a contrasting increase from 2019 to mid-2022. This further establishes that this research interest has only been given the attention it deserves during the past 3–4 years. The color variation from light to dark reflects a low to a high number of publications. So it is seen that in 2022, the highest number of articles were published in relation to variation one, while for variation two, the highest number of publications so far were recorded in 2022. Hence, this technology is of high value, and its practical use is necessary to provide satisfactory encouragement.

Table 2. Colored document frequency matrix of publications between 2013 and 2022.

	Variation 1	Variation 2
2022	88	23
2021	72	20
2020	38	13
2019	26	7
2018	13	4
2017	8	2
2016	8	5
2015	2	0
2014	0	0
2013	0	0

Moreover, two variations in specific keywords were used to explore the co-occurrence of different keywords connected to the research on BGI and urban flooding. The co-occurrence maps in Figure 8 below illustrate the co-occurrence network map of BGI for keyword variation one. It was clustered, with several nodes defining the link between the main keywords. The thickness of the links defines the link strength between keywords. “BGI” and “GI” are the two main components of the network, as per the map generated. The map also highlights the relevance of other concepts, such as “ecosystem services”, “stormwater management”, “flood risk management”, “flooding”, and “blue-green cities”. Centrality is an indicator of the connections that a node has with the other components of the network. In this case, it could be translated as the transversality of the concept among all the topics. It means it is a term with a high co-occurrence with most other issues on the map. Figure 8, where variation one is considered from the global perspective, shows the robust connectivity of BGI, green infrastructure, and flood risk management by depicting the strong bond/ link between them in red.

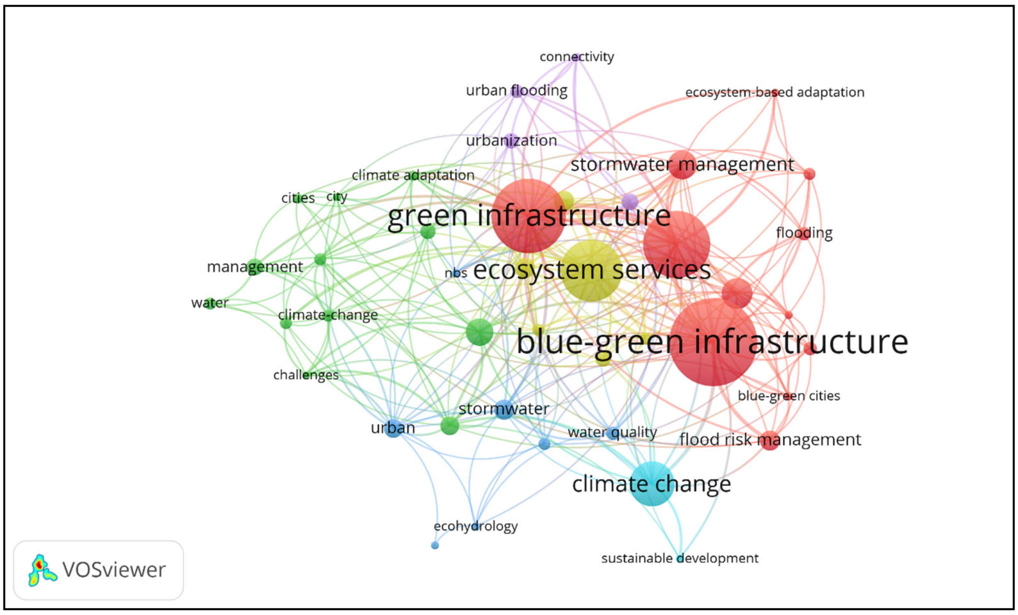

Figure 8. Co-occurrence network map of BGI: version 1.

Accordingly, the co-occurrence map for keyword variation two, as in Figure 9, was generated to compare the Australian research context of BGI with the global BGI research context. The network implies that Australia does not explicitly network with BGI but only with "green infrastructure" instead. However, the illustration reveals that the co-occurrence with "nature-based solutions" and "resilience" is more robust with the GI in Australia.

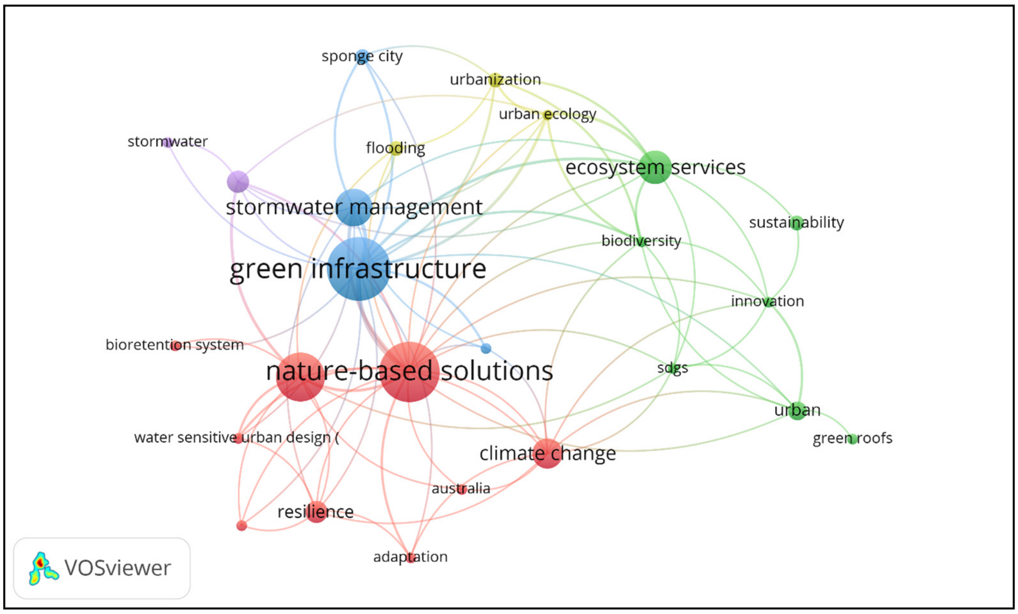

Figure 9. Co-occurrence network map of BGI: version 2.

5. Conclusions

Water management is a primary responsibility for all cities around the globe, whether it be for reducing flood risk, enhancing access to clean water, or treating urban water effluents. Local governments, international organizations, and non-governmental organizations are becoming more interested in nature-based solutions for effective and sustainable urban water management (ADB, 2019). BGI is one of the technical strategies available for flood mitigation and is an integrated management system, which has no barriers to using technology mixed with ecology. It negligibly impacts the environment. BGI necessitates a proactive search for novel ways to include nature in solutions through researchers, practitioners, and policymakers working together.

Therefore, Australia, a highly vulnerable country to unprecedented floods, can implement BGI as an effective and environmentally sound technique. Moreover, BGI supports quality of life and improved environment, health, and well-being. Therefore, BGI is not only applicable to address flood mitigation, but it also actively heightens the quality of the urban environment. However, on the other hand, to gain proper awareness or education about this technique, the authorities and other stakeholders must be convinced that this mechanism significantly assists the environment and addresses the issue. Other than that, policies about such implementations should be necessarily altered, and other policymakers should support this strategy as an effective way to restrain the post-effects of floods, including damage to the country's environment, humans, health, infrastructure, and economy.

Furthermore, as an effective strategy in flood mitigation, this study depicts that more attention should be given to this concept of BGI by encouraging scientific research and applications in the real world. However, from the global perspective and in the Australian context, the number of research papers published during the last decade is satisfactorily adequate. They critically question the assistance and guidance of countries in implementing this beneficial long-term strategy.

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