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Advancing flood resilience: the nexus between flood risk management, green infrastructure, and resilience

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Introduction: Climate change and the fast pace of urbanization are two major factors contributing to the exacerbated risk of flooding in urban areas. Flood resilience strategies, underpinned by the principles of green infrastructure, are gaining importance as within broader spatial planning approaches, and various global cities are adopting revised policies and frameworks to improve flood risk management. Yet, such responsive approaches are still limited and context-specific.

Methods: In this article, thematic analysis using NVivo was employed to analyse 49 documents related to flood risk management, resilience, and green infrastructure planning.

Results: This paper reflects on the concepts of flood risk management, flood resilience and green infrastructure planning to identify the synergies between these concepts, and identify challenges that are prohibiting global flood resilience.

Discussion: Enhancing flood resilience requires coordinated efforts, effective communication, and collaborative governance among stakeholders. The paper also draws planning recommendations for advancing flood resilience through governance and an integrated planning approach, in support of the global goals toward flood resilience.

KEYWORDS

climate change, green infrastructure, flood resilience, governance framework, flood risk management

1. Introduction

The effects of climate change are becoming increasingly pronounced and causing more severe disasters in cities across the globe. Climate change impacts are driven by various changes relating to the climate system, including changes in the water cycle, atmospheric circulation, ocean, cryosphere, biosphere and modes of variability (Hunt and Watkiss, 2011; Arias et al., 2021). Although there is a common thought about human-induced climate change, it is a continuing mechanism that affects ecosystems and communities worldwide (Wang et al., 2019). Climate change impacts are related to six categories, namely floods, heatwaves, drought, hurricanes, wildfires, and loss of glacial ice [Hunt and Watkiss, 2011; National Oceanic and Atmospheric Administration. Climate change impacts (NOAA), 2022]. These climate change impacts are often related to loss of life, physical and emotional suffering, property damage, decreased productivity, environmental degradation, loss of species and habitats, damage to infrastructure, a weakened economy, disrupted community coherence, political instability, and reduced quality of life [Commonwealth Attorney-General's Department, and Australian Institute for Disaster Resilience (AIDR), 2017].

On average, climate-related events displace 23.1 million people each year, with 9.8 million being the result of hydrometeorological hazards and disasters (World Meteorological Organisation, 2021). In recent decades, the frequency of natural disasters recorded globally

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has sharply risen, and the continuous pattern will lead to further significant individual and social costs (Degg, 1992; Bănică et al., 2020). According to Pörtner et al. (2022) and the State of Climate by Australian Bureau of Meteorology and Australian Commonwealth Scientific and Industrial Research Organisation (BOM and CSIRO) (2020), flood risks and other climate change impacts will continue to increase.

Flooding poses an especially great risk in urban areas since it has the potential to affect a larger population, for instance; Brazil can serve as a representative example of countries encountering comparable difficulties, such as significant rural-to-urban migration resulting in unsustainable urban growth and inadequate urban stormwater drainage systems in regards to their ability to handle water conveyance and preserve water quality (Vasconcelos et al., 2022). According to the report of the latest flood in Alagoas, Brazil, which occurred in July 2023, over 20,000 people were affected by floods caused by heavy rains, resulting more than 3500 people being displaced (Davies, 2023).

Moreover, based on the report by Economics (2017), the yearly economic losses caused by floods have been calculated to be more than those caused by cyclones, storms, bushfires, and earthquakes combined, and resulted in an annual cost of $8.8 billion for Australia in 2017. Furthermore, it is estimated that 160,000 properties in Australia are currently at risk of damage (Hazard, 2018). The recent flood events in the greater Sydney areas have been costly to the local communities with the social and financial impacts. La Niña was a contributing factor to these recent floods and damages, with daily rainfall in the states of New South Wales and Australian Capital Territory witnessed an increase of over 97 percentiles leading to a significant surge in daily extreme rainfall in 2022 across these regions (Australian Bureau of Meteorology (BOM), 2023).

It is crucial to search for solutions and discover methods that deliver urban flood resilience, through a deep investigation of vulnerability and adaptive capacity (Kotzee and Reyers, 2016). This paper reflects on the concepts of flood risk management, flood resilience and green infrastructure planning to identify the synergies between these concepts, and identify challenges that are prohibiting global flood resilience.

2. Research methodology

This paper followed a literature review pertaining to concepts of flood risk management, flood resilience and green infrastructure planning. Initially, 228 documents were identified for analysis, based on the keywords "climate change," "green infrastructure planning," "flood risk management," and "flood resilience" within Google Scholar, Google platform, Science Direct, Wiley Online Library and the library of the University of Technology Sydney. This analysis was refined with the inclusion of keywords "climate adaptation" and "nature-based solutions" in addition to the previous keywords leading to the identification of 194 documents. The keyword "governance" was accordingly added leading to 49 documents which were included in the final analysis, based on their approach to governance of flood risk management, flood resilience and green infrastructure planning. Figure 1 provides a more detailed breakdown of the analysis process.

These 49 academic documents, including academic articles, books, technical project reports, independent reviews of recent flooding events, relevant guides, and standard handbooks, were imported in NVivo. NVivo is a Computer-Assisted Qualitative Data Analysis Software (CAQDAS) program that designed to facilitate qualitative research through supporting code-based inquiry, searching, theorizing, and providing the capability to annotate and edit documents (Richards, 1999). In this analysis 37 nodes[1] were identified (refer to Table 1).

From the initial analysis, a word frequency assessment was conducted across 37 nodes to identify key terms central to the research. This analysis highlighted specific words, such as "floods," "managing," "risks," "plan," "governments," and "water" with a corresponding weighted percentage. The purpose of Table 2, presented below, is to provide a concise summary of these word frequency findings. By examining the frequency of these terms within the dataset, valuable insights into the prevailing discourse on flood resilience and green infrastructure planning are gained. This analysis forms a critical foundation for the research findings and contributes significantly to the understanding of the topic, paving the way for practical applications in real case study areas and potential integration with complementary methodologies like the Delphi method.

3. Thematic analysis

The thematic analysis focused on flood risk management, flood resilience and green infrastructure planning as accordingly captured. The thematic analysis investigated all of these concepts in terms of global status, and local status in Australia and New South Wales. The interface between these concepts were accordingly analyzed, in an attempt to draw conclusions about the interface and disjoints between these concepts.

3.1. Flood risk management

Previously, flood risk management strategies were centered around a "keep floodwater out" approach, incorporating "hard engineering solutions" as part of water management and planning principles. This approach was not effective in managing and controlling the level of vulnerability and the intricacy of flooding (Freitag et al., 2012; Lennon et al., 2014). These resistance-based strategies were adopted in flood risk management approaches, drawing on gray infrastructure and engineering (Freitag et al., 2012; Lennon et al., 2014) to control flood threats, as well as to control behavior through laws and regulations (Holling and Meffe, 1996). Although the resistance approach provided some protection against floods, it was questioned if this is an adequate approach given the uncertainty introduced by climate change and the costs associated to saving human lives, property and infrastructure, in the event

1 Nodes (or Codes): Within NVivo, "nodes" (sometimes referred to as "codes") serve as labels or categories applied to specific segments of text in qualitative data analysis. These nodes facilitate the organization and categorization of information, aiding in the identification of recurring themes, patterns, and insights within the dataset.

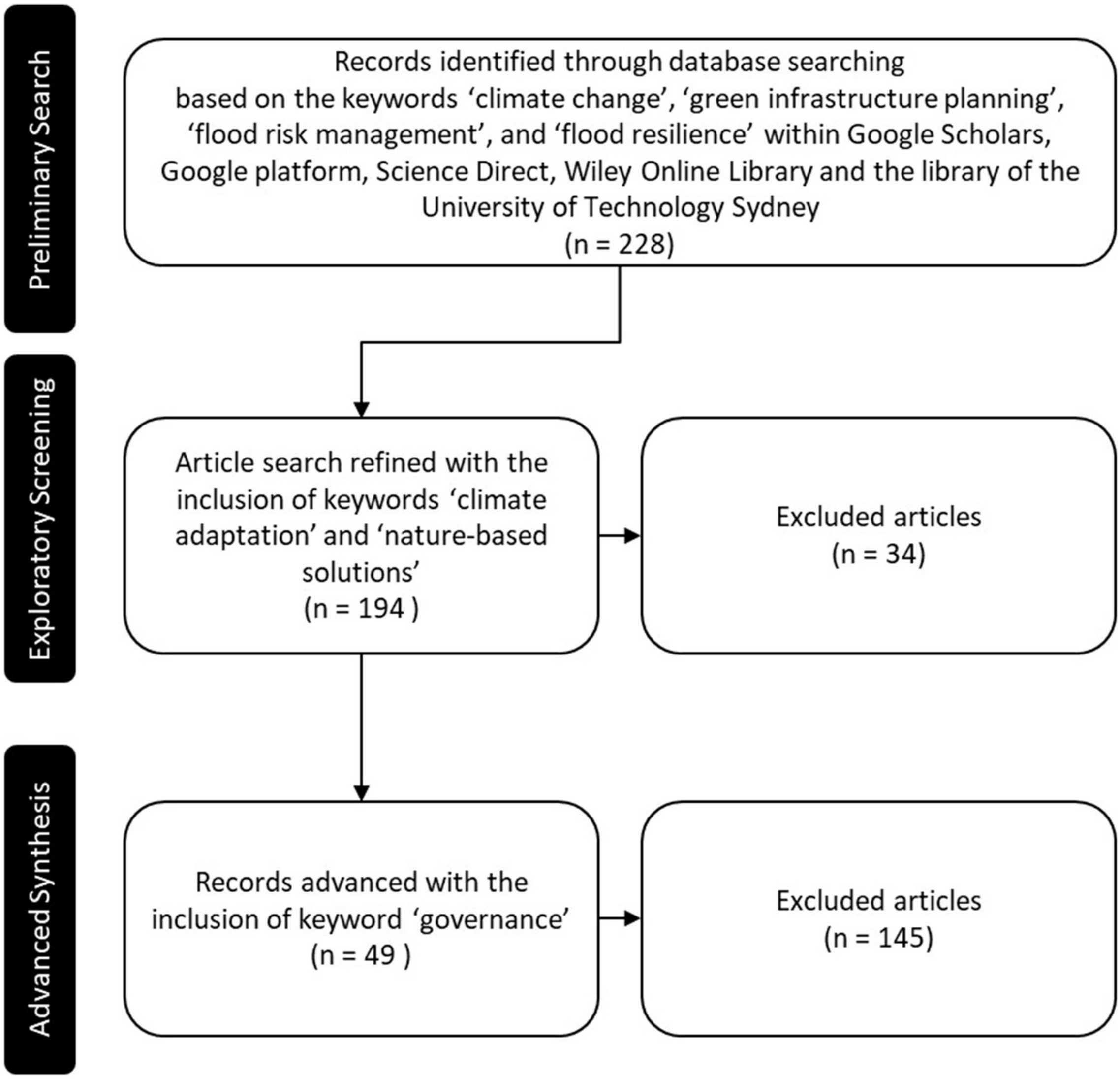

FIGURE 1
Research design flowchart. Source: Developed by authors based on Haddaway et al. (2017).

that the capacity of the resistance system is exhausted (Morrison et al., 2018). As a result, the flood resilience approach has emerged as a more integrated, comprehensive and strategic approach that amalgamates both resistance-based and adaptive-based strategies to improve flood risk management (Schelfaut et al., 2011; Liu et al., 2020).

The flood risk management strategies are mainly classified as prevention, defense, mitigation, preparation, and recovery (Larrue et al., 2016; Matczak and Hegger, 2021). Pörtner et al. (2022), highlights the importance of incorporating green infrastructure components as part of risk management strategies, stating that concepts such as green roofs and facades, park and open space networks, urban forest and wetland management, and urban agriculture, should be incorporated into broader sustainable urban planning and infrastructure design, in quest to mitigate flood risks.

At the same time, stormwater management has undergone significant changes as a result of modifications in the nature of cities, the growing population, and the increasing frequency and intensity of flooding (Radcliffe, 2019). Initiatives relating to retention, smart stormwater management in the long-term, as well as reuse within the urban water cycle has gained importance. Various stormwater management plans have been redesigned with a greater focus on green infrastructure, as illustrated in Table 3.

3.2. Flood resilience

Resilience refers to a system ability to withstand and recover from possible damage and disruptions, as well as maintain normal operations to the greatest extent (Buckle et al., 2000; Liao, 2012). The concept of resilience in managing natural resources, recognizes that human and natural systems are complex and constantly evolving through changes (Walker et al., 2006). Resilient systems can adapt and respond to shocks and critical threshold,

TABLE 1 Nodes in NVivo for the analysis of 49 documents.

Nodes	Documents	References[a]
Climate change impacts	15	29
Climate change adaption	8	11
Flood risk and stormwater management	15	46
Flood risk and water governance	19	124
Barriers or issues for flood risk governance	22	169
Opportunities for flood risk governance	21	200
Flood risk management principles	1	1
Stormwater management methods	4	12
Nature-based solutions	13	30
Blue-green solutions	3	8
Green infrastructure	10	48
Adaptive urban green infrastructure planning	3	11
Scale of green infrastructure planning	8	13
Green infrastructure planning principles	3	21
Green governance or sustainable urban growth management	11	47
Solutions or opportunities for sustainable or green infrastructure planning	15	137
Drivers	7	18
Constellations	2	3
Barriers for sustainable or green infrastructure implementation	14	119
Sustainable urban growth indicators and indices	4	10
Resilience	7	14
Urban resilience	4	7
Adaptive governance	12	28
Flood resilience	9	12
Flood resilience governance	13	30
Opportunities for flood resilience	14	78
Barriers for flood resilience	12	37
Flood resilience indicators	1	5
Flood resilience tools	1	2
Method	24	34
Data collection	19	31

(Continued)

TABLE 1 (Continued)

Nodes	Documents	References[a]
Data analysis	6	9
Quantitative	4	9
Qualitative	22	39
Mixed-method	3	3
Result and discussion	27	55
Transdisciplinary approach	1	5

[a]References in this table refer to the number of times a specific node or code has been applied to segments of qualitative data in NVivo. In essence, it indicates how frequently a particular theme or concept appears within the data.

TABLE 2 Word frequency in analyzed 49 documents.

	Word	Count	Weighted percentage (%)
1	Floods	10,467	1.84
2	Managing	5,690	1.00
3	Risks	5,494	0.97
4	Plan	5,068	0.89
5	Governments	4,382	0.77
6	Water	4,351	0.76
7	Urbanizing	3,648	0.64
8	Develops	2,942	0.52
9	Policy	2,814	0.49
10	Greening	2,539	0.45
11	Changing	2,483	0.44
12	Local	2,412	0.42
13	City	2,237	0.39
14	Levels	2,184	0.38
15	Resilient	1,984	0.35

transforming from one stable state to another and continuously learning through this adaption process (Walker and Salt, 2012; van Veelen et al., 2015).

The idea of resilience was introduced into urban planning in the 1990s (Mileti, 1999) and has since gained attention in research and practice (Potter and Vilcan, 2020). To strengthen resilience through landscape and urban planning, planners and designers need to recognize the potential challenges, conflicts and disruptions a particular landscape or city may face, including their frequency and severity, and find ways for the city to adapt and respond to these disturbances while still maintaining a resilient state (Vale and Campanella, 2005; Ahern, 2011).

Resilience planning is tailored to each community, and context, as each has its own distinct identity, characteristics, and needs. This can be accomplished by incorporating considerations of potential shocks and stresses into the community's planning process, including its plans, zoning regulations, development standards, incentive programs, and other policies and guidelines.

TABLE 3 List of stormwater management plans with green infrastructure focus based on analysis of 49 documents.

Area	Stormwater management methods and plans	Description	References
United States of America	LID: Low Impact Development	The strategy is based on maintaining the natural hydrologic system in urban areas to reduce the effects and potential stormwater damages and minimize pollution on watershed ecosystems	Dietz, 2007; Roy et al., 2008; Davis et al., 2009; Ahiablame et al., 2012; Ahiablame and Shakya, 2016; Radcliffe, 2019; Darnthamrongkul and Mozingo, 2021; Koc et al., 2021; United States Environmental protection Agency (EPA), 2023
United Kingdom	SuDS: Sustainable Drainage Systems	The environmentally friendly and aesthetical systems and practices that use or mimic natural processes that result in the infiltration, evapotranspiration or use of stormwater	Martin, 2000; Defra, 2005; Rauch et al., 2005; Mitchell, 2006; O'Donnell et al., 2017; Li et al., 2020; Gimenez-Maranges et al., 2021
Australia	WSUD: Water Sensitive Urban Design	An approach to planning and designing urban areas to make use of this valuable resource and reduce the harm it causes to rivers and creeks	Wong, 2006; Wong and Brown, 2009; Thurston, 2011; Coutts et al., 2013; Wong et al., 2013; Gersonius et al., 2016; Zhang et al., 2021
New Zealand	LIUDD: Low Impact Urban Design and Development	An environmentally sensitive approach to managing urban stormwater by introducing rain gardens, green roofs, open swales, detention ponds and using ecologically friendly pervious surfaces	Ignatieva et al., 2008; van Roon and van Roon, 2009
European Commission	BGI: Blue-Green Infrastructure	A network of both strategic and planned infrastructure designed to protect bio-diversity, deliver ecosystem services and provide multiple social services	Hoyer et al., 2011; Brown et al., 2016; Brears, 2018; Drosou et al., 2019; United Kingdom Joint Nature Conservation Committee (JNCC), 2019; Potter and Vilcan, 2020; Dar et al., 2021; Flores et al., 2021
United States of America	BMP: stormwater Best Management Practices	Stormwater management approaches use natural processes to mitigate stormwater runoff and water quality	Hoyer and Dickhaut, 2010; Rodrigues et al., 2021; Shojaeizadeh et al., 2021
China	SCP: Sponge City Program	The stormwater management approach creates wet infrastructures to capture, store, and hold rainstorms to prevent disastrous flooding	Wang et al., 2013, 2018; The State Council of the People's Republic of China, 2015; Li et al., 2016; Onuma and Tsuge, 2018; Sallustio et al., 2019; Sun et al., 2020; Stewart et al., 2021
South Africa (RSA)	WSS: Water Sensitive Settlements	Urban water management resources through the integration of the various disciplines of engineering, and social and environmental science	Armitage et al., 2014; Carden et al., 2018
Brazil	Green Infrastructure	Network of wetlands, known as "humedales" have been incorporated into urban fabric and serve to manage stormwater, filter pollutants, and provide habitat for a variety of species	Ramírez et al., 2013; Turcios et al., 2021

Two main perspectives have been identified in the study of the linkage between resilience and urban planning (Cruz et al., 2013). The first viewpoint focuses on the integration of human and environmental goals, exploring the relationship between resilience and socio-ecological systems (Pickett et al., 1997; Holling and Gunderson, 2002; Alberti and Marzluff, 2004; Berkes, 2007). The second perspective concentrates on the relationship between resilience and spatial planning, providing principles for becoming more resilient. Furthermore, Davoudi et al. (2012) emphasized that regulating interconnected socio-ecological systems through physical and geographical boundaries, is crucial for resilient-urban planning.

According to Liao (2012), in the context of flood hazard management based on resilience, periodic floods are seen as opportunities for cities to improve their ability to withstand extreme floods. There are three viewpoints on urban flood resilience: (a) Engineering resilience refers to a system's capacity to return to stability after being disturbed by floods, (b) Ecological resilience refers to the flexibility of a natural system to be robust and flip into another domain of stability, and (c) Socio-ecological resilience system highlights the role of the local community in

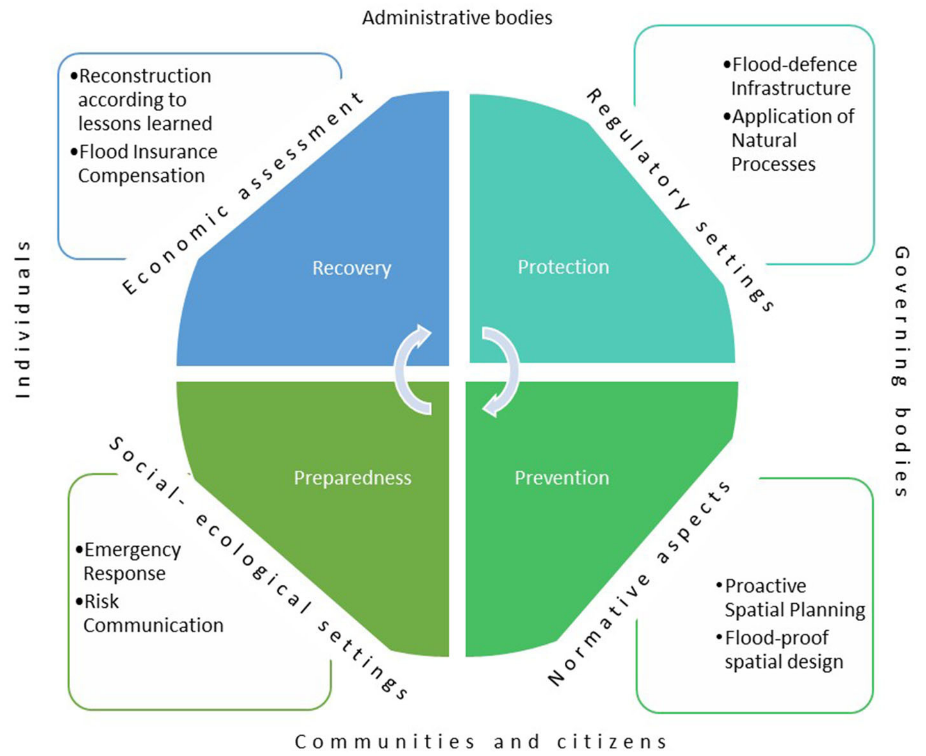

FIGURE 2
The Flood Resilience Rose. Source: Developed by the authors based on Karrasch et al. (2021).

creating opportunities for innovation and development in response to disturbances (Folke, 2006; Davoudi et al., 2012; Index, 2014; Vitale et al., 2020). Moreover, resilience as robust concept was identified in three main categories: (1) Engineering resilience, (2) Systems resilience, and (3) Complex adaptive systems resilience (Matczak and Hegger, 2020; McClymont et al., 2020). Based on this category, flood resilience is defined as capacity to resist, capacity to absorb and recover, and capacity to transform and adapt (Alexander et al., 2016b; Hegger et al., 2016; Zevenbergen, 2016).

Smart urban development presents ways to achieve resilience in the events of floods (Balsells et al., 2015). In a resilient city, disasters, such as floods, are considered opportunities to enhance the city's sustainability and promote growth (Serre et al., 2012). It calls for multi-layer methods to analyse flood management from different scales. At the parcel or block scale, the evaluation considers building function, while at a larger scale, such as the city scale, it considers five dimensions: natural, physical, economic, social and institutional dimensions (Batica et al., 2013). The Flood Resilience Rose was created by Karrasch et al. (2021) as a management tool for actors and institutions working in the river and coastal zone management, to comprehend the complexity and interconnectivity of the different dimensions and scales related to flood resilience (see Figure 2).

3.3. Green infrastructure planning

Previously stormwater management approaches mainly relied on hard-engineering solutions such as culverts, sewer systems and large-capacity river, stream, and urban drainage channels (Jones and Macdonald, 2007). However, with time, the idea of "making space for water" and the integration of green infrastructure gained prominence (Flores et al., 2021). Green infrastructure is defined by Benedict and McMahon (2012) as a network of natural areas and other urban open spaces such as urban forests, grasslands, and agricultural lands. This network helps preserve the functioning of natural ecosystems and offers a variety of benefits to the general public (Benedict and McMahon, 2012). Based on the extensive benefits green infrastructure provides, such as reducing the impact of urban heat islands, lowering the need for cooling in buildings, improving resistance to storms through natural water absorption, minimizing runoff and untreated stormwater overflows into water bodies, and even providing a local source of food (Rouse and Bunster-Ossa, 2013), green infrastructure and related ecosystem services became increasingly important factors in the management of stormwater and creation of resilient urban areas (Green et al., 2021).

The development of green infrastructure has gone through three stages since 1850 (Sun et al., 2020) (Figure 3). Since the 1990s, it has been a crucial component in stormwater management methods such as Low Impact Development and stormwater Best Management Practices that originated in the USA, Sustainable Drainage Systems that originated in the UK, Water Sensitive Urban Design that originated in the Australia, Low Impact Urban Design and Development that originated in the New Zealand, Blue-Green Infrastructure that originated in the European Commission, Sponge City Program that originated in the China and Water Sensitive Settlements that originated in the South Africa

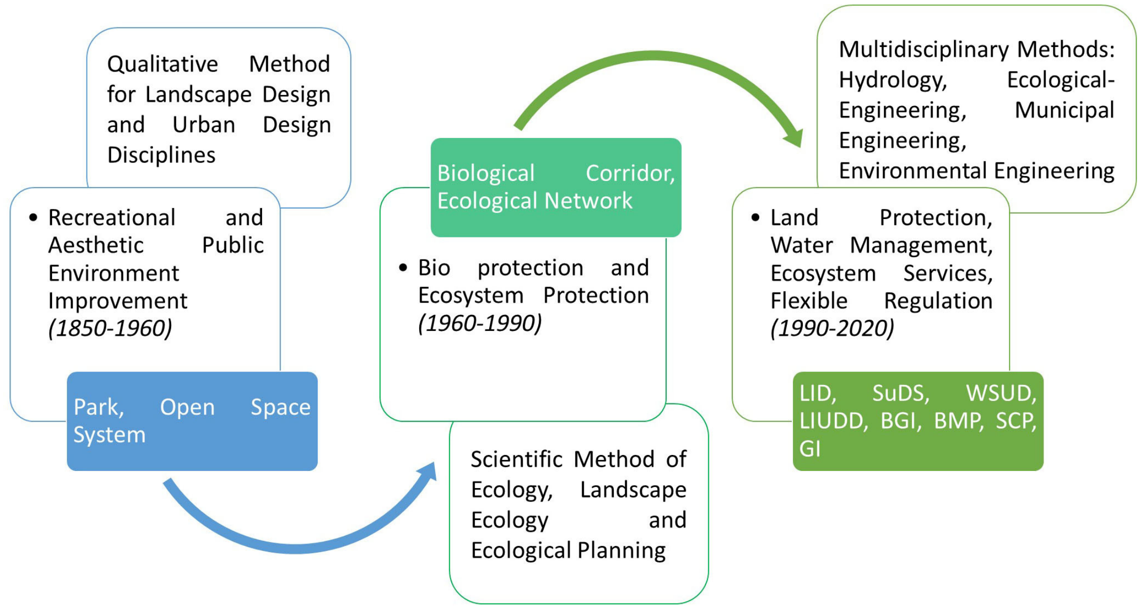

FIGURE 3
The development stages of green infrastructure. Source: Developed by authors based on Sun et al. (2020).

(Mell, 2017; Choi et al., 2021). Green infrastructure has been recognized as a core approach in the quest toward sustainable development (Williamson, 2003; Dawson et al., 2014; Perveen et al., 2017).

The concept of green infrastructure has been recognized as one of the key strategies for realizing sustainable development and has been set as a more sustainable approach of managing floods compared to traditional hard infrastructures methods (Marsalek and Chocat, 2002). Green infrastructure is known to reduce the negative impacts of natural disasters and has positive outcomes on the health, well-being, economy, social-wellbeing of urban dwellers (Parker and Zingoni de Baro, 2019).

The utilization of green infrastructure approaches in flood risk management is also recognized as a method that involves the combination of natural processes to protect, revive and emulate or recreate waterways such as coastlines, rivers and floodplains. This results in a nature-based solution that not only preserves the natural ecosystem value but also lessens the flood risk (Green et al., 2021). As a result, green infrastructure is considered a multi-objective and comprehensive planning method that encompasses different types of urban green areas at various scales (Hansen and Pauleit, 2014; Artmann et al., 2019), including micro, macro and meso levels (Mabaso et al., 2021). In essence green infrastructure remains a public asset that provides environmental, community, and economic benefits to city dwellers (Tackett, 2009; Cilliers and Cilliers, 2016; Cilliers, 2019; Newman et al., 2019). This highlights the importance of considering green infrastructure from a holistic perspective, and accommodating relevant inputs and perspectives through adaptive planning and design (Ahern et al., 2014).

Successful green infrastructure planning approaches relates to four key principles; integration, connectivity, multifunctionality, and participation (Ahern et al., 2014; Government Architect New South Wales, 2020). The principle of integration promotes the coordination of green spaces with other infrastructures, such as transportation and utilities to ensure a harmonious alignment between urban systems; integration involves a mutual exchange of information to achieve a desirable outcome (Index, 2014; Ambrose-Oji et al., 2017). Connectivity focuses on creating a unified network of open and green spaces, while multifunctionality prioritizes the provision of multiple benefits by combining different urban functions and reducing conflicts between green infrastructure and other infrastructures. Participation, on the other hand, involves an open and inclusive planning process that allows for collaboration and input from a variety of stakeholders (Ambrose-Oji et al., 2017). These four principles should be considered in broader spatial planning approaches (Monteiro et al., 2020) to promote sustainability and resilience.

4. Discussion

The management of urban flood resilience is complex and requires coordination at multiple levels, including proactive and practical policy entrepreneurs, the use of clear guidelines and rules, and the allocation of resources (Dieperink et al., 2018). To address these challenges, it is important to have clear and hierarchical relations, coordinating bodies, and a shared vision and strategy for water management (Alexander et al., 2016a; Matczak et al., 2016). In reflecting on the concepts of flood risk management, flood resilience and green infrastructure planning, the following points are highlighted as a way forward to enhance the interface between these concepts and approaches:

4.1. Coordination and communication

Improving flood resilience can be achieved through effective communication between scientists and practitioners, by adopting governance practices that are tailored to the existing physical, socio-cultural, and institutional context (Driessen et al., 2016). Consequently, research shows that many technical experts such as engineers are not fully embracing green infrastructure in their plans and even if they exhibit a willingness to implement green infrastructure, their efforts continue are hindered by a conventional way of thinking and are unable to address the complexities and spatial scales involved (Cousins, 2018). The aforementioned barriers to effective and sustainable stormwater governance include a lack of integration between governance systems and the communities they affect, unclear roles and responsibilities among various organizations, and a lack of motivation among stakeholders (Fitzgerald and Laufer, 2017; Prudencio and Null, 2018). In addition, fragmented governance systems (Ek et al., 2016) and changing hydrological schemes often face financial challenges, such as the inability of urban planners and decision-makers to allocate funds for green infrastructure improvement (Campbell et al., 2016; Zhang et al., 2017).

Political inconsistencies of unaligned borders (and scope) of various disciplines, professions, policy and legislative frameworks are further complicating the realization of broader flood resilience. In Australia, for example, the planning of stormwater management, flood risk management and flood resilience has been based on various strategies, guidelines and policies. These include the "Flood Emergency Planning for Disaster Resilience Handbook" [Australian Government Department of Home Affairs, and Australian Institute for Disaster Resilience (AIDR), 2020a] which again draws on several other strategies such as "Australian Emergency Management Arrangements [Australian Government National Recovery and Resilience Agency, and Australian Institute for Disaster Resilience (AIDR), 2023]," "Public Information and Warnings [Australian Government National Recovery and Resilience Agency, and Australian Institute for Disaster Resilience (AIDR), 2021]," "Land Use Planning for Disaster Resilient Communities [Australian Government Department of Home Affairs, and Australian Institute for Disaster Resilience (AIDR), 2020b]," "National Emergency Risk Assessment Guidelines [Australian Government Department of Home Affairs, and Australian Institute for Disaster Resilience (AIDR), 2020d]," "Evacuation Planning [Australian Government Attorney-General's Department, and Australian Institute for Disaster (AIDR), 2017]," "Emergency Planning [Australian Government Department of Home Affairs, and Australian Institute for Disaster Resilience (AIDR), 2020c]," "Community Recovery [Australian Government Department of Home Affairs, and Australian Institute for Disaster Resilience (AIDR), 2018]," and "Community Engagement for Disaster Resilience [Australian Government Department of Home Affairs, and Australian Institute for Disaster Resilience (AIDR), 2020e]." It is a complex environment to navigate all stakeholders involved and it highlights the importance of coordination and communication between these different stakeholders, in recognizing and addressing the different levels of resilience to build community and municipal resilience, as the lack of recognition could leave some communities more vulnerable, and less resilient.

In this regard, scholars emphasized the collaborative governance concept as a method to assess and analyse collaboration among public and private sectors in dealing with uncertainty and surprise (Ansell and Gash, 2008; Hutter, 2016).

4.2. Collaborative governance

Recently the trend in urban management has shifted from a centralized government to governance; as the government struggles with the complex challenges posed by globalization and the need for input from multiple stakeholders and the general public (He et al., 2010). Governance refers to the system or framework in which different individuals or groups involved in the creation and execution of flood risk management policies operate and collaborate effectively with other stakeholders (Vinke-de Kruijf et al., 2015; Ishiwatari, 2019).

Scholars have emphasized that good governance, along with social and policy learning are crucial to achieving flood resilience (Wallington et al., 2007; He et al., 2010). Research on flood risk governance, also highlighted the role of governance frameworks in promoting the integration of green infrastructure and flood resilience, emphasizing the importance of different stakeholders such as government agencies, private sector actors, and community groups, in implementing green infrastructure as a flood resilience strategy. Governance encompasses a broad range of processes, foundations and institutions, strategies and policies, and relationships that inform decision-making and action-taking in environmental and social systems (Armitage et al., 2012; Morrison et al., 2018; Bottazzi et al., 2019). It involves, established plans and regulations that promote collaboration among stakeholders by aligning their conflicting interests (Li et al., 2018). Furthermore, effective flood resilience governance requires collaborative processes, stakeholder's engagement, a mix of top-down and bottom-up approaches and decentralized approach, transparency, capacity building, inclusive governance and decision-making process, equity, and social legitimacy (Hartmann and Spit, 2016; Ng, 2016; Edelenbos et al., 2017; Dobre et al., 2018; Rodina, 2019).

A study by Driessen et al. (2018) states that there are six governance strategies to enhance flood resilience: (1) diversifying flood risk management, (2) aligning flood risk management to reduce fragmentation in policy making (Rondinelli, 1973; Mees et al., 2016), (3) involving and cooperating with both public and private actors in flood risk management, (4) having formal rules that balance legal certainty flexibility, (5) ensuring sufficient financial and other types of resources, (6) adopting normative principles to address distributional effects. This study called the STAR-FLOOD project (2012–2016), focused on governance and legal issues and considered the responsibility of governments in Belgium (Mees et al., 2016), England (Alexander et al., 2016a), France (Larrue et al., 2016), The Netherlands (Kaufmann et al., 2016), Poland (Matczak et al., 2016), and Sweden (Ek et al., 2016). These studies involved a thorough analysis and evaluation of flood risk governance and legal frameworks in the aforementioned countries at the national level and in three urban areas in each country at the local level.

TABLE 4 Approaches to enhance broader flood resilience.

	Green governance
Approach	Opportunities
Enhanced coordination and communication among stakeholders	Strengthen coordinated and aligned communication among stakeholders by creating a sense of shared ownership, transparency, and trust
Strengthened collaborative governance	Prioritization and goal alignment through a clear understanding of the various perspectives and interests, and by developing integrated and collaborative approaches that create synergies and minimize trade-offs
Prioritize trans- disciplinarity	Make a transparent delineation of roles and responsibilities through developing clear and vibrant institutional arrangements, with well-defined roles and responsibilities for different actors, including the public sector, civil society, and the private sector
Grant applications and fundraising	Resource mobilization and innovative financing through including public-private partnerships, leveraging private sector capital and expertise, reducing the burden on public finances, and creating new sources of funding for green investments
Enhanced robust regulatory framework	Establishment of regulatory frameworks through developing clear standards and guidelines, monitoring and enforcement mechanisms, and appropriate penalties for non-compliance

4.3. Trans-disciplinary approaches

The integration of principles of urban climate change resilience and green infrastructure planning, can enhance a city's ability to function effectively (Abunnasr, 2013; van Herk et al., 2014). This calls for a trans-disciplinary approach to enhance urban green infrastructure, to realize its potential to mitigate the risk of flooding in growing metropolitan areas (Schubert et al., 2017; Vitale et al., 2020). As discussed, stormwater was once viewed as a problem, hazard, or waste, but recent advancements in urban planning, politics, and technical expertise have shifted toward treating stormwater as a resource instead of a nuisance (Cousins, 2018). The integration of stormwater management and GI strategies is becoming a globally adopted approach to urban water governance, aimed at improving water quality regulations (Cousins, 2018; Shi, 2020). This approach not only helps to mitigate the effects of extreme weather events like heavy rain and flooding, but also proves to be cost-efficient (Rayan et al., 2021). The integration of stormwater management and green infrastructure is a promising solution that balances and buffers the effects of extreme weather and promotes climate change resilience (Semadeni-Davies et al., 2008; Dreiseitl, 2015; Ossa-Moreno et al., 2017; Wihlborg et al., 2019). As argued by Ibrahim et al. (2020) for the successful implementation of green infrastructure, green governance is essential.

5. Limitations and future research directions

Flood resilience is a relatively under-explored field of research, with limited existing studies directly exploring the connection between flood risk management, flood resilience, and green infrastructure (Wise, 2008; Sayers et al., 2013; Pörtner et al., 2022). Nevertheless, it is a rapidly evolving and interdisciplinary domain that encompasses environmental science, urban planning, civil engineering, and social sciences, necessitating a wide range of expertise (Edelenbos et al., 2017; Dieperink et al., 2018; Rayan et al., 2021). The practical implementation and evaluation of strategies related to these concepts can be complex, time-consuming, and context-dependent. However, this research serves as a valuable starting point for shedding light on the nexus between flood risk management, green infrastructure, and resilience.

While this literature review has provided valuable insights into the governance of flood risk management, flood resilience and green infrastructure planning, it is essential to acknowledge certain limitations that may have influenced the findings and interpretations. Firstly, the reliance on online platforms, particularly Google Scholar, may have led to an over-presentation of certain literature references, potentially biasing the review toward more widely available or prominently indexed sources. Moreover, the dynamic nature of the field and the evolution of knowledge over time may have resulted in the exclusion of recent studies or emerging research that were not yet indexed or readily accessible. Additionally, despite efforts to conduct a comprehensive search, the availability of literature on the subject matter might have been restricted, especially when exploring less-studied aspects of this research. These limitations underscore the need for caution in generalizing the conclusions and highlight the importance of staying current with the evolving literature to build upon and refine our understanding of this study. Future research endeavors should consider exploring diverse databases and employing multiple search strategies to address these limitations and ensure a more comprehensive examination of the topic.

6. Conclusion

Flood resilience strategies, underpinned by the principles of green infrastructure, are gaining importance within broader spatial planning approaches, and various global cities are adopting revised policies and frameworks to improve flood risk management. Governments are adopting practical solutions to become resilient to the impacts of climate change, particularly floods. Yet, such responsive approaches are still limited and context-specific. Different countries are using various approaches based on their environmental context, governmental system and community vulnerability. The challenges facing green infrastructure and its long-term sustainability are complex and potentially conflicting, emphasizing the need for Green Governance as a way forward. The true meaning of green governance, originated in open innovation and is achievable when the procedure of governance-decision and actions are working collaboratively, and funding is integrated effectively into various segments to tackle environmental issues (Li et al., 2018). However, centralized governance or being restricted in bottom-up or top-down approaches, high costs, lack of funding, and lack of knowledge and expertise are significant barriers to green governance (Wihlborg et al., 2019). Barriers to green governance can be complex and multifaceted, spanning across challenges relating to a lack of coordination and communication among stakeholders, conflicting priorities and goals, limited resources and funding, weak regulatory frameworks, and a lack of clear delineation of roles and responsibilities. Other factors such as population growth, climate change, and economic pressures further impact the success of green governance initiatives. The nature and severity of these barriers can vary depending on the specific context and location, and effective strategies for overcoming them will need to be tailored accordingly. By addressing these barriers, green governance can create new opportunities for broader flood resilience, as illustrated in Table 4.

In addressing these challenges Green Governance should be positioned to adequately consider the potential benefits and challenges of implementing green infrastructure strategies, using natural solutions like wetlands as well as employing combination of green-hard infrastructure such as permeable pavements to reduce flooding, and examining how these strategies can be integrated into broader flood risk management governance frameworks. It also requires understanding of the complex socio-ecological systems involved in flood risk management and how different stakeholders can collaborate to create more resilient urban environments. This research highlights the importance of advancing flood resilience through green governance and an integrated planning approach, in support of global goals toward flood resilience.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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