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Building flood-resilient cities by promoting SUDS adoption: A multi-sector analysis of barriers and benefits in Bogotá, Colombia

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ABSTRACT

In light of rapid urbanization and climate change, managing urban flood risk by combining traditional pipe-bound infrastructure with sustainable urban drainage systems (SUDS) has recently gained significant attention. SUDS provide a wide range of social, economic, and environmental advantages; nonetheless, there are perceptions, barriers, and benefits whose understanding is lacking, especially in the context of developing countries. To fill these gaps, a case study was conducted in the city of Bogotá, Colombia's capital city, systematically investigating the visions of four key actors, i.e., the public sector, urban developers, a private non-profit organization, and community members of a flood-prone area. Thematic analysis supported by an inductive–deductive coding approach was employed to analyze data collected from in-depth semi-structured interviews and questionnaires. After identifying and categorizing 39 barriers in Bogotá, technical and institutional/organizational barriers such as "operation and maintenance" and "unclear institutional responsibilities" prevailed over financial ones. The assessment of benefits yielded a total of 34 results and demonstrated the wide scope of SUDS strategies, ranging from "use of harvested water in secondary uses" to "promotion of environmental awareness" and "corporate image enhancement." Furthermore, there are direct relationships between barriers, benefits, and actors, strengthened by particular objectives, motivations, and needs. The findings of this study highlight the significance of interdisciplinary approaches to achieve comprehensive sustainable urban water planning and improved flood risk management. Further work on benefits quantification and participatory spatial-hydraulic modeling could foster SUDS interest, broadening the debate beyond the technical realm.

1. Introduction

Urban flooding is a growing concern influenced by factors such as climate change [1,2], urban growth [3,4], changes in land use [5,6], and mismanagement of spatial planning [7,8]. In Colombia, additional geo-climatic and institutional factors, i.e., the La Niña/El Niño weather phenomenon and limited risk management capacity, have triggered unprecedented rain-related effects such as those evidenced in the 2011 floods, affecting more than three million people [9,10]. By 2050, 68% of the world's population is projected to be urban [11], and a greater concentration of people and infrastructure increases the exposure to flood risk [12]. Adverse impacts of flood events include loss of human life, economic damages, interruption of critical infrastructure, and environmental degradation

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[13,14]. Therefore, there is a global challenge to find adaptative solutions to cope with multiple hydrometeorological hazards [15] and the effects of human activities [16].

In this sense, researchers have proposed novel approaches for sustainable urban water management (SUWM) such as green infrastructure (GI), blue-GI (BGI), low impact development (LID) techniques, nature-based solutions (NbS), and sustainable urban drainage systems (SUDS) [17–23]. SUDS are multi-objective strategies for reducing runoff quantity, enhance stormwater quality, provide amenity, and increase biodiversity in urban spots [24]. Attenuation storage tanks (AST), green roofs (GR), and rainwater harvesting systems (RWHS) are the most common SUDS typologies for residential, commercial, and public facility use [25]. Other SUDS typologies that require more space and are thus better suited to outdoor land include bioretention systems (BRS), constructed wetlands (CW), extended dry basins (EDB), infiltration basins (IB), infiltration trenches (IT), pervious pavements (PP), ponds (P), tree pits (TP), and vegetated swales (VS) [26]. Depending on the scale and land use distribution, these strategies can be implemented on public or private land under an individual or interconnected (SUDS trains) scheme [24].

SUDS research has largely focused on technical aspects such as performance assessment, i.e., reduction of runoff volumes and flow peaks [27,28]; selection, location, and size optimization [26,29]; co-benefits evaluation [30,31]; and cost-benefit analysis [32]. Furthermore, the study of SUDS has been led for several decades by developed countries such as Australia, Canada, the United Kingdom, and the United States [33]. In contrast, developing countries have shown an incipient interest in the full spectrum of SUWM. For instance, pilot projects in Malaysia [34], Kenya [35], and Colombia [26] have stressed the importance of employing sustainable management of stormwater in tandem with pipe-bound systems, considering the particular challenges of unsustainable urban expansion, land tenure, and space constraints. Nevertheless, despite the evidence of the multiple advantages over conventional approaches, SUDS implementation has a slow pace and a weak overall interpretation, even in developed contexts [23,36].

It is still unclear which factors assist or hamper the integration of alternative stormwater management strategies in urban environments [37]. Understanding the barriers allows for the identification of factors that delay the adoption of SUWM alternatives [38], whereas assessing the perceived benefits enables one to recognize the particular needs of urban water-related sectors [39]. Several authors analyzing the context of developed countries claim that the transition to sustainable drainage approaches is hindered by socio-political rather than technical constraints [36,40,41]. Furthermore, a wide variety of benefits have been demonstrated, ranging from the well-known functions of runoff reduction and flood control [36] to property value enhancement [31,39]. However, there is a lack of studies in other socio-economic and governance contexts.

Another factor that has been identified as critical for SUWM to achieve long-term effects is the involvement and participation of multiple stakeholders [31,42–44]. SUWM requires interdisciplinary approaches to integrate the visions of actors who often have conflicting interests [31] and to strengthen the related decision-making process [44]. The review performed by Sarabi et al. [43] identified four types of actors at micro-, meso-, macro-, and transboundary scales in the application of NbS that aid in the co-planning and co-management of this type of infrastructure. Furthermore, Venkataramanan et al. [45] highlighted the use of interdisciplinary approaches to increase GI uptake, improve design, and provide a better understanding of the multidimensional benefits. Nevertheless, approaches to developing resilient solutions remain technocratic [21,46], with few studies systematically investigating the diversity of opinions.

Considering the aforementioned gaps, this study aims to investigate the perceived barriers and benefits of SUDS implementation in Bogotá, Colombia, through the lenses of four key actors, i.e., the public sector, urban developers, a private non-profit organization, and community members living in a flood-prone area. The contribution of this research is threefold: i) expand the body of literature on factors that promote or stymie the transition to SUWM; ii) conduct a comprehensive assessment of experiences and knowledge from relevant urban water stakeholders; and iii) perform the analysis within the context of a developing city. To achieve this, semi-structured interviews and questionnaires were used as data collection methods, and thematic analysis supported by an inductive–deductive coding approach was employed to analyze the gathered data.

The remainder of the paper is structured as follows: Section 2 presents the rationale for the analysis of barriers and benefits of SUDS implementation based on a thorough review of the existing literature. In Section 3, we describe the case study, the participant sectors, and the data collection and analysis methods. Section 4 and Section 5 present the results and discussion of the multi-sector analysis of barriers to and benefits of SUDS implementation. The paper concludes with Section 6, which summarizes the findings and contributions of the study.

2. Barriers to and benefits of SUDS implementation

Understanding the barriers to and benefits of SUDS implementation is key to successful urban water planning, improved decision- and policy-making in flood risk management, and fostering large-scale adoption [23,35,37,47,48]. The assessment presented in this study is based on an exhaustive literature review addressing these factors in the implementation of sustainable stormwater controls in urban environments such as GI, BGI, LID techniques, NbS, and SUDS.

Barriers are those factors that delay [38], hamper [37], or block [49] the adoption of SUWM strategies. The identification and assessment of barriers allow for the anticipation of challenges that may arise during the planning or implementation stages [50]. Previous studies addressing the barriers to implementation of BGI [23,41,51], LID techniques [37], and SUDS [52] have listed multiple constraints and evidenced the need to classify them to achieve an accurate understanding. Such categorization is useful as many barriers are systemic or embedded in organizational cultures [53]. The present study adopted six categories to classify the barriers to SUDS implementation (Table 1): cultural/behavioral, financial, institutional/organizational, political, technical, and urban form. Cultural/behavioral barriers reflect individual beliefs or perceptions, derived from a local context of time and space [49]. Financial barriers involve constraints associated with financing and the costs of SUDS implementation [51,53]. Institutional/organizational barriers stem

Table 1
Barriers to SUDS implementation.

Category	Barriers to SUDS implementation
Cultural/behavioral barriers	Lack of community ownership
	Lack of interest in SUDS
	Lack of private sector engagement
	Negative SUDS perceptions
	Path dependency
	Silo mentality
	Uncivil behaviors
Financial barriers	Financial burden
	Lack of financial resources
Institutional/organizational barriers	Inflexible and conflicting rules
	Lack of consultation
	Lack of design standards and guidance
	Lack of institutional coordination/communication
	Lack of supportive policy and legal framework
	Lack of regulatory binding instruments
	Position of power of the water utility
	Responsibility vs. authority dilemma
	Unclear institutional responsibilities
Political barriers	Electoral/administrative changes
	Lack of political leadership/will
Technical barriers	Diverse interpretations of the SUDS concept
	Efficiency uncertainty
	Lack of general knowledge
	Lack of local experience/benchmarks
	Lack of operational capacity
	Lack of quantitative evidence/performance information
	Lack of technical capacity
	Operation and maintenance
	Space constraints
	Workload that SUDS demand
Urban form barriers	Private land ownership
	Public land ownership
	Urban densification

from institutional dynamics, whether inter-governmental or inter-departmental [54], whereas political barriers are derived from government decisions or positions [23,47]. Technical barriers are related to the planning, implementation, and operation of SUDS [49], whereas urban form barriers refer to the built environment hindrances [54]. As observed, barriers to SUDS implementation cross multiple fields of knowledge [50] and may be related to or stem from one another [17,48]. Full descriptions and references for each barrier are listed in Supplementary material, Table A1.

On the other hand, the benefits of implementing SUWM strategies represent factors that influence greater adoption [51], prominent drivers to promote upscaling interventions [55], and aspects that should be considered to achieve a successful multifunctional design [36]. Literature addressing the benefits of GI [31,36], NbS [55], and SUDS [26,32] has highlighted a wide range of advantages, beyond stormwater runoff control and flood management. Numerous studies have employed the ecosystem services categorization (provisioning, regulating, supporting, and cultural) [56] for the assessment and valuation of these benefits [32,57,58]. Nevertheless, commercial, market-related, or economic advantages may lag behind under this classification. The present study adopted a three-dimensional categorization of SUDS benefits (Table 2) in accordance with the three dimensions of sustainability [31,36,51]: economic, environmental, and social. The economic benefits consider any type of cost reduction triggered by the implementation of SUDS [59]. The environmental benefits refer to the improvement of biodiversity and ecological resilience [36]. Social benefits refer to the promotion of well-being and a healthier lifestyle for users [55]. The multifunctionality of SUWM strategies allows these benefits to occur in parallel; however, it should be noted that the classification shown in Table 2 is not intended to be universal but rather an indicator of the benefits that may be more evident. Full descriptions and references for each benefit are listed in Supplementary material, Table A2.

The preceding list of barriers and benefits, as well as their respective categories, laid the foundation of this study. Nevertheless, since these two factors are highly dependent on the local context, it is natural for additional barriers and benefits to emerge during the analysis process, as will be demonstrated in the following sections. Therefore, this research contributes not only to the regional SUWM debate in cities with similar socio-economic and governance characteristics but also to the comprehensive participatory planning of urban environments in other contexts.

Table 2
Benefits of SUDS implementation.

Benefits of SUDS implementation	Type of benefit		
	Economic	Environmental	Social
Air quality enhancement			X
Amenity			X
Aquifer recharge		X	
Biodiversity augmentation		X	
Climate change adaptation and mitigation	X	X	X
Decentralized water supply	X	X	X
Flood risk mitigation	X		X
Health and well-being improvement			X
Heat resilience	X		X
Noise reduction			X
Peak flow reduction	X		X
Promotion of ecosystem services		X	X
Promotion of environmental awareness		X	X
Promotion of multifunctional spaces	X	X	X
Recreation opportunities	X		X
Reduction in water treatment costs	X		
Runoff volume control	X		X
Stormwater management		X	
Tax reduction	X		
Use of harvested water in secondary uses	X	X	X
Water quality enhancement	X	X	X

3. Methods

The multi-sector analysis of barriers to and benefits of SUDS implementation was conducted in the context of Bogotá, the capital city of Colombia. Data collection methods included semi-structured interviews and questionnaires, whereas thematic analysis supported by an inductive–deductive coding approach was employed to analyze the gathered data.

3.1. Case study description

Bogotá is Colombia's capital and largest city, with a population of 7,181,469 inhabitants [60]. It is one of the Latin American metropolises, along with Buenos Aires, Mexico City, Santiago, and São Paulo, sharing similar features of urban growth, informal employment, and land privatization [61]. Nonetheless, the urbanization process of Bogotá has been different compared to Lima and Quito, owing to its high-density compact development pattern [62]. Its geographical location at the foothills of the Andes has limited urban expansion, resulting in a striking phenomenon of densification [63,64] and the development of informal settlements in unsuitable construction areas [63]. These characteristics, intensified by the population growth pressure, have negatively impacted 80% of the wetlands in the city [63] and, consequently, approximately one million people live in flood-prone areas [65].

The climate of Bogotá is categorized as cold–very dry. The mean temperature is 13.1 °C, and the mean annual total rainfall is 797 mm [66]. The city has a bimodal climate with two dry seasons (January–February and July–August) and two rainy seasons (March–June and September–December). In order to ensure compliance with national FRM regulations, since 2007 the local authorities have performed a series of conventional river flood controls, i.e., channeling, hydraulic adaptation, and expansion of sewerage coverage, managing to reduce the fluvial flood risk level [67]. Nonetheless, the rainy season in December 2011, aggravated by the La Niña phenomenon, triggered the Fucha River backflow and several sewer system failures, affecting approximately 18,000 households [68]. In addition, pluvial flooding and waterlogging events are recurrent in the second rainy season because of the limited capacity of the drainage network [69].

Although integration of SUWM in urban planning processes is slow-paced in the Latin American region [61], multiple strategies have emerged in Bogotá within the framework of the sustainable development goals (SDGs), climate change, and urban water management. For instance, the Local Secretary of Environment implemented in 2014 the Bogotá Sustainable Building Program, aiming to promote biodiversity preservation and the incorporation of native species into urban projects. In addition, decree 528 of 2014 together with decree 088 of 2017, have leveraged SUDS as sustainable stormwater drainage strategies. Furthermore, the local water utility issued regulations for the design and construction of SUDS in 2018. As a great local and national milestone, the most recent Bogotá land-use plan (a road map to plan and order the territory between 2022 and 2035) designated liability for the construction and maintenance of SUDS both on public and private land.

Considering the above, Bogotá represents a city committed to addressing the challenges of sustainability and climate change. Therefore, the assessment of barriers and benefits of SUDS implementation might aid other developing cities in the context of stormwater management, disaster resilience, and urban planning.

3.2. Selection of participants

Reflecting on the need to incorporate interdisciplinary approaches to foster a wider SUDS adoption [31,42], the multi-sector analysis considered the participation of the public sector, urban developers, a non-profit organization, and members of the community.

The selection of the public sector interviewees considered the hybrid governance structure described by Van de Meene et al. [70] to achieve an effective transition to SUWM. This incorporates three different approaches, i.e., hierarchical, network, and market governance, combining the provision of a formal administrative framework, interdisciplinary collaboration, and the efficient use of resources, respectively. In this way, local institutions/authorities with capacities in one or more of the previously described approaches were identified based on official information on SUDS pilot projects in Bogotá. A snowball sampling approach [71,72] allowed for the validation of this initial list. Then, a mapping exercise was performed through a two-dimensional matrix [73,74], linking the institution's potential to foster SUDS implementation and its influence on the related decision-making process. Fig. 1 displays all assessed public stakeholders, i.e., the Local Secretary of Environment (LSE), the Local Secretary of Planning (LSP), the Local Water Utility (LWU), the Urban Development Institute (UDI), the Urban Development and Renovation Company (UDRC), and the Local Institute for Risk Management and Climate Change (IRMCC). Of the four relevant SUDS management bodies, contact was possible with the LSE, LWU, and UDI.

At the private sector level, this study focused the analysis on urban developers due to their influence on city planning and development [75] and because the adoption of SUWM alternatives remains a challenge within this type of stakeholder [76]. The invitation to participate was extended to five large companies, the most influential locally and nationally, but only three were confirmed. Furthermore, the Colombian Green Building Council (CGBC), a private non-profit organization with high national and international influence in urban planning and sustainable construction, was contacted.

Several authors have highlighted the necessity of addressing SUWM through a balanced top-down and bottom-up approach [21,51]. Understanding the perceptions, motivations, and needs of the community is key to exploring opportunities for the co-creation and management of solutions [77], beyond the information-sharing role [38]. Therefore, members of a flood-prone community living in Bosa, one of the 20 administrative divisions (*localidades*) in Bogotá, were contacted for participation in this study. Since 2002, Bosa has had the highest concentration of people affected by flood events due to the poor performance of the drainage system and the direct influence of the Tunjuelo River, one of the tributaries of the Bogotá River [67]. In addition, in 2012, 89.14% of the dwellings belonged to strata 2 [78], a socio-economic classification that relates people's quality of life to the quality of the home they live in, with 1 being the lowest category and 6 the highest. The convergence of these socio-economic and risk conditions points to an imminent need to evaluate novel FRM strategies that consider local context characteristics and community perceptions.

3.3. Data collection

3.3.1. Semi-structured interviews

This study employed online in-depth semi-structured interviews with the public sector representatives (LSE, LWU, and UDI), the three urban development companies, and the private non-profit organization in the field of sustainable construction (CGBC). Interviews are one of the most common qualitative data collection methods, widely used in different disciplines, offering participants the opportunity to express themselves and discuss their opinions in an out-of-ordinary context [79]. Following social distancing protocols

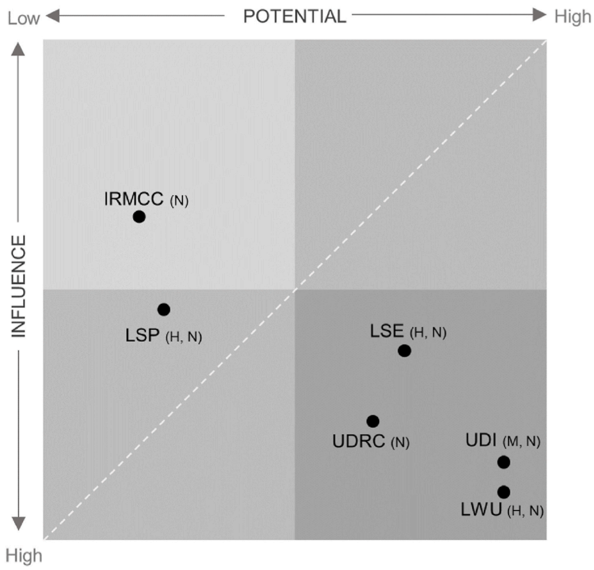

Fig. 1. Mapping of public stakeholders in Bogotá for SUDS management, including potential governance approaches [70]: H (hierarchical), N (network), and M (market).

based on COVID-19 restrictions, the use of video conference platforms is suitable for the approach, allowing data collection in real time, even with multiple participants in different locations [80]. The semi-structured interviews in this study were conducted through the Zoom platform under the license acquired by the University of Bonn, allowing recordings and meetings for more than 40 min (the limit for free licenses). This technological consideration, along with stable connectivity [81], was decisive for rapport building by allowing communication without involuntary time constraints and focusing on participants' attention.

All semi-structured interview participants were contacted via email first, and after acceptance, time was scheduled at their convenience and informed consent was sent. All interviews were conducted in Spanish, audio-recorded using a digital voice recorder (Sony ICD-PX470), and video-recorded with the Zoom feature as an additional backup with the participants' consent; field notes were taken simultaneously. Semi-structured interviews ($n = 10$), individual and in groups, were conducted between November 2020 and March 2021, lasting 40–96 min, with the participation of 15 interviewees. A set of open-ended questions was asked, along with prompts and follow-up questions, allowing participants to explore details that had not been initially elicited [82]. Questions to public sector interviewees sought to understand FRM competencies, SUDS knowledge, perceived benefits and barriers, and current regulations. Urban development companies were inquired about management strategies within the framework of the SDGs, green building certifications (GBC), strategies to mitigate land-use changes, SUDS knowledge, perceived benefits and barriers, and regulation awareness. The interview with the GCBC sought to understand its competencies, partnerships, GBC processes, SUDS knowledge, common SUDS strategies in construction projects, and perceived barriers and benefits.

The visual aid was employed to facilitate the recognition of SUDS typologies. Details of the interviews are presented in Table 3, along with the alphanumeric codes for participant identification to maintain confidentiality.

3.3.2. Questionnaires

In this study, questionnaires were distributed in person to members of a flood-prone community living in Bosa. Before the pandemic, this study had conceived FGD to collect data from the community sector. Nonetheless, considering COVID-19 regulatory constraints, a questionnaire technique was implemented outdoors, complying with all distancing and hygiene protocols. Although questionnaires are a quantitative research technique, their implementation with open-ended questions was intended to reflect the plurality of visions rather than show statistical significance [83].

Initial contact with the Bosa community started via email through the Bosa Mayor's Office, giving a brief introduction to the project and inquiring about existing environmental community-led initiatives. Then, at the invitation of a spokesperson, questionnaires were distributed on April 3, 2021, as part of the closing event of an official project called "Huertas Urbanas" (Urban Farms). Community attendance was not as expected, so most of the participants interviewed ($n = 13$) were part of the organizing staff of the event, who were also local residents. The questionnaire was written in Spanish and included 19 questions comprising background information, multiple-choice, and open-ended questions [51,84] to capture local knowledge about flood experiences, flood risk awareness, SUDS knowledge, and perceived benefits and barriers to implementation. Conversations were voice recorded with the informed consent of each participant, and field notes were taken simultaneously. Graphic materials were provided to recognize pre-selected SUDS. For anonymity, empirical evidence provided by the community participants was represented by alphanumeric codes ranging from C1 to C13.

3.4. Data analysis

We adopted thematic analysis (TA) supported by an inductive-deductive coding approach to analyze the data collected from semi-structured interviews and questionnaires. TA aims to identify, analyze, and report patterns (themes) within data [85]. It is a flexible yet rigorous approach that can be used to address most types of qualitative research questions [86]. TA has proven to be a robust and flexible method for drawing sound conclusions with implications for urban water decision- and policy-making [51,87–89]. TA includes a coding process in which the data is organized into meaningful groups in a systematic fashion [90]. This can be accomplished through a data-driven (inductive) approach when the themes depend on the data or through a theory-driven (deductive) approach, in

Table 3
Semi-structured interview details.

Date	Key actor	Sector	Interviewee code	Position/Department
19-11-2020	Colombian Green Building Council (CGBC)	Private non-profit organization	PR1	Technical director
			PR2	Technical leader
27-11-2020	Local water utility (LWU)	Public sector	PU1	Specialized Engineer
30-11-2020	Local water utility (LWU)	Public sector	PU2	Specialized Engineer
14-12-2020	Urban development company #1	Urban developer	UD1	Planning department director
			UD2	Planning coordinator
			UD3	Technical specialist
15-01-2021	Local Secretary of Environment (LSE)	Public sector	PU3	Specialized Engineer
21-01-2021	Urban development company #2	Urban developer	UD4	Vice President of Innovation and Operations
21-01-2021	Urban Development Institute	Public sector	PU4	Specialized engineer and SUDS specialist
25-01-2021	Urban development company #2	Urban developer	UD5	Special business manager
28-01-2021	Urban development company #3	Urban developer	UD6	Urban development director
			UD7	Project manager
			UD8	Development manager
20-03-2021	Local water utility (LWU)	Public sector	PU5	Social management coordinator

which the researcher addresses the gathered information with specific questions in mind [85]. Since the successful integration of SUWM is strongly influenced by the study area context [51], inductive-deductive reasoning serves to comprehensively address multi-stakeholder perspectives in data-scarce environments, nourished by local experience and knowledge and existing evidence from other contexts (Section 2).

All semi-structured interview and questionnaire recordings were fully transcribed verbatim after each session, supported by the field notes. These were edited to remove repetitions and irrelevant habitual phrases [89] while maintaining accuracy. The transcripts were analyzed using the foundational model of qualitative data analysis described by Kalpokaite and Radivojevic [91], which combines an inductive–deductive coding approach. Atlas.ti version 9.1.7.0, a widely referenced text encoding software, was used for analysis [51,72,92]. Fig. 2 displays the followed steps. We started by developing a code book from existing literature [54] on barriers to and benefits of SUDS implementation (Tables 1 and 2). A pre-coding process was performed to identify significant segments of the data. Then, a parallel process of initial coding and elaborative coding was performed, the latter with the aid of the code book. The “revision and grouping codes” stage is an iterative process in which the context of a code becomes relevant for its modification, elimination, or permanence within the final code list, whereas “focused coding” seeks to create data categories. After this process, network development allows visualizing links between codes. Memoing is an integral part of the entire coding process to keep track of decisions made during data analysis.

A complementary quantitative analysis of excerpt counts was also performed to determine the frequency with which a specific issue is addressed. This was intended to draw a topic's relevance rather than participants' position to it [36,82].

4. Results

The exploration of perceived benefits and barriers related to SUDS implementation differed for each examined sector. Questionnaires conducted with community participants included questions inquiring about their perceptions about RWHS, GR, and BRS, as they are the SUDS typologies that best suit private land within a built environment. Semi-structured interviews with urban developers inquired about previous evaluation and implementation of eleven SUDS typologies previously analyzed in the context of Bogotá's public and private land [26], namely, AST, BRS, CW, GR, IB, IT, P, PP, RWHS, TP, and VS. In both cases, the open-ended question format allowed for the exploration of the reasons and motivations framing their perceptions. In the case of public sector representatives and the private non-profit organization, interviews did not explore specific SUDS typologies even though an open-ended question was asked inquiring about the most commonly used typologies based on the institution/company scope.

Direct quotations were used to provide robustness [89] and clarify key points made in relation to the selected themes [85]. After transcribing from the original Spanish, we did not attempt to change the grammar or expressions [93]. Respondents were identified alphanumerically, as described in Table 3 and Section 3.3.2. In some cases, the number of codings (excerpt counts) referring to a certain topic is also displayed in parentheses following this notation: (c = number of codings).

4.1. Analysis of perceived barriers

Barrier identification was enabled by a previously developed code book derived from the literature (Table 1) and when participants used statements that included words such as “affect,” “barrier,” “burden,” “challenge,” “complicated,” “difficult,” “dilemma,” “doubts,” “impossible,” “inconvenience,” “lack of,” “limiting,” “obstacle,” “problem,” “resistance,” “unfortunately,” and “worries” [53]. The inductive–deductive coding process yielded 39 barriers linked to 275 codings.

The distribution of barriers by category according to the inquired sectors is shown in Fig. 3. Although the number of interviewees is heterogeneous among the participating sectors, this analysis is intended to portray the joint vision of four key sectors not only to foster SUDS uptake but also to improve understanding of SUWM, land-use, and built environment decision-making. Technical and institutional/organizational barriers received the most mentions, mostly from the public sector representatives and urban developers. Nonetheless, the analysis highlighted the significance placed on cultural/behavioral barriers, primarily by the public sector participants. Financial barriers, commonly considered as a great obstacle in sustainable-related projects, ranked fourth in the general analysis.

Community members and public sector professionals mentioned barriers in all six categories even though the number of total mentions differs from one sector to another, 34 and 175, respectively. Note that the public sector was represented by five interviewees from three different entities, whereas the community sector had the participation of 13 members. This suggests that when participants are more exposed to a given topic, the plurality of their opinions and perceptions increases. The data collection method may also be related to this phenomenon because, despite having a specific question to investigate the perceived barriers, the environment

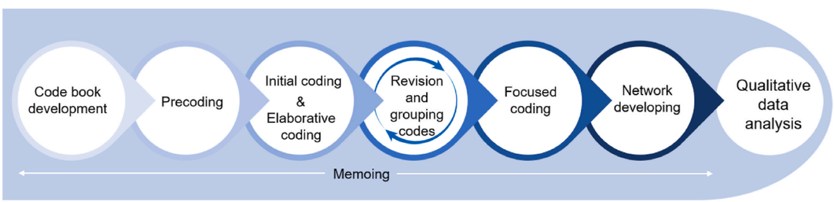

Fig. 2. Adaptation of the foundational model of qualitative data analysis from Kalpokaite and Radivojevic [91].

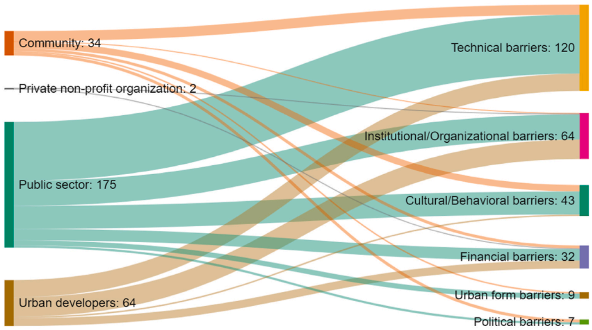

Fig. 3. Distribution of barrier codings by category according to the inquired sectors.

provided by the interviews to share individual experiences allows interviewees to explore additional information that may not have been initially considered [94].

Of the participants, professionals from the private non-profit organization made the fewest barriers references. This may be related to number of participants and to their consulting role in assisting the public and private sectors in developing public policies either for the built environment or new urban projects (PR1, PR2).

Table 4 summarizes the complete list of barriers and their respective excerpt counts. The thematic analysis allowed for the elucidation of six barriers that were not previously included in the code book, namely, "clogging effect," "increase in water tariffs," "indoor humidity conditions," "performance reduction," "risks to conventional drainage system performance," and "waterlogging/inundation problems." The following sections will examine the most relevant barriers and interconnections according to each participating sector.

4.1.1. Perceived barriers by community members

As previously stated, community members mentioned barriers in all six categories. Interestingly, the most frequently reported barrier was the "lack of community ownership" (c = 6), followed by the "lack of general knowledge" (c = 5), which has cultural implications and may be related to the "lack of interest in SUDS" (c = 2). Public education and awareness campaigns may aid in addressing these limitations. It is noteworthy that knowledge dissemination is commonly relegated to SUDS champions, who mostly belong to academia or the public sector. This represents an opportunity to develop government-led initiatives not only to raise awareness but also to encourage further community participation in planning, implementation, surveillance, operation, and/or maintenance.

On the other hand, some participants also mentioned governance concerns related to the "lack of political leadership/will" (c = 3) and "electoral/administrative changes" (c = 1). In the words of participant C13: "there may be economic, institutional, and public resources, but if there is no political will, nothing can be done." This suggests a lack of trust in the local administration that can interfere with educational efforts and any public initiative. The provision of different communication channels may strengthen dialogue between these two types of actors.

Regarding the urban form barriers, two participants emphasized "private land ownership" issues, e.g., living under a horizontal property regime. This suggests that the analysis of SUDS' potential for private land such as GR or RWHS should consider not only the availability of private land but also land tenure implications. In turn, the "lack of financial resources" (c = 4) was accompanied by factors such as the "lack of technical capacity" (c = 3), "workload that SUDS demand" (c = 1), and "efficiency uncertainties" (c = 1), demonstrating the importance of knowledge in overcoming negative perceptions.

It should be noted that although participants were questioned about three specific SUDS typologies, i.e., RWHS, GR, and BRS, barriers such as "lack of community ownership," "uncivil behaviors," "lack of consultation," "electoral/administrative changes," and "lack of political leadership/will" can be considered hindrances preventing interest and participation in any type of project, whether it is a private initiative or a government-led program.

4.1.2. Perceived barriers by a private non-profit organization

The interview with the private non-profit organization was attended by two participants with high expertise in the field of sustainable construction practices. They discussed the financial burden that SUDS implementation may represent for urban developers because it is more difficult to increase the return on investment (ROI) of water-related strategies than it is for energy efficiency measures. According to PR1, since "water is unfortunately low-priced," it would be more effective to increase urban developers' interest from a normative perspective. It is worth noting that, at the national level, the water supply and sanitation regulations stipulate that new urban developments are required to mitigate the effect of soil imperviousness through the implementation of SUDS [95]. However, this has exacerbated institutional barriers such as "inflexible and conflicting rules" (UD7) and the "responsibility vs. authority dilemma" (PU2).

The private non-profit organization's participants also mentioned the "position of power of the water utility" as a barrier: "When working with urban projects, the water utility is not so interested in being handed over SUDS vs. other types of water management structures" (PR1). This hindrance might be related to cultural/behavioral barriers such as "path dependency" and "silo mentality" that prevent the evaluation of SUWM strategies, coupled with a lack of technical knowledge. Some authors also refer to this as "risk aversion" or "resistance to change" [96]. This appreciation was confirmed when interviewing one of the LWU representatives: "The

Table 4
Summary of barriers hindering SUDS implementation.

Category	Perceived barriers	C (*np* = *13*)	PR (*np* = *2*)	PU (*n p* = *5*)	UD (*np* = *8*)	ec
Cultural/behavioral barriers	Lack of community ownership	6	–	1	–	7
	Lack of interest in SUDS	2	–	–	1	3
	Lack of private sector engagement	–	–	3	–	3
	Negative SUDS perceptions	–	–	7	–	7
	Path dependency	–	–	4	–	4
	Silo mentality	–	–	9	–	9
	Uncivil behaviors	1	–	8	1	10
Financial barriers	Financial burden	–	1	9	11	21
	Increase in water tariffs	–	–	1	–	1
	Lack of financial resources	4	–	6	–	10
Institutional/organizational barriers	Inflexible and conflicting rules	–	–	–	4	4
	Lack of consultation	1	–	–	–	1
	Lack of design standards and guidance	–	–	1	5	6
	Lack of institutional coordination/communication	–	–	6	–	6
	Lack of regulatory binding instruments	–	–	5	–	5
	Lack of supportive policy and legal framework	–	–	3	4	7
	Position of power of the water utility	–	1	7	3	11
	Responsibility vs. authority dilemma	–	–	7	–	7
	Unclear institutional responsibilities	–	–	6	11	17
Political barriers	Electoral/administrative changes	1	–	2	–	3
	Lack of political leadership/will	3	–	1	–	4
Technical barriers	Clogging effect	–	–	3	1	4
	Diverse interpretations of the SUDS concept	–	–	15	1	16
	Efficiency uncertainty	1	–	6	–	7
	Indoor humidity concerns	1	–	–	–	1
	Lack of general knowledge	5	–	3	2	10
	Lack of local experience/benchmarks	–	–	–	1	1
	Lack of operational capacity	–	–	4	1	5
	Lack of quantitative evidence/performance information	–	–	4	–	4
	Lack of technical capacity	3	–	6	1	10
	Operation and maintenance	–	–	21	14	35
	Performance reduction	–	–	3	3	6
	Risks to conventional drainage system performance	–	–	6	–	6
	Space constraints	3	–	2	–	5
	Waterlogging/inundation problems	–	–	2	–	2
	Workload that SUDS demand	1	–	7	–	8
Urban form barriers	Private land ownership	2	–	4	–	6
	Public land ownership	–	–	1	–	1
	Urban densification	–	–	2	–	2
Total number of codings		34	2	175	64	275

C: community members; PR: private non-profit organization; PU: public sector representatives; UD: urban developers; np: number of participants; ec: excerpt counts.

conventional drainage system is designed to operate for a lifespan of 50 years; the equipment for its maintenance is already known. In the case of the SUDS, there is little knowledge" (PU1).

4.1.3. Perceived barriers by public sector representatives

As well as for community members, technical barriers received the highest number of mentions from the public sector (c = 82). Their considerations are primarily based on the short experience with local pilot projects and perceptions about future scenarios in which the implementation of SUDS is massive. In this sense, "operation and maintenance (O&M)" is the most concerning barrier among the LWU, LSE, and UDI. According to the co-occurrence analysis, O&M had direct links to eight additional barriers, as shown in Fig. 4. These connections are supported by the interviewees' quotations (See Supplementary material, Table B1). Interestingly, O&M was related to cultural/behavioral, financial, institutional/organizational, and technical barriers, with the latter being the most influential.

From the perspective of the LWU, there is a lack of local-context quantitative evidence regarding O&M, which might be exacerbated by the "lack of financial resources" and scarce technical and operational capacity. Participants PU1 and PU2 were also concerned about the "workload that SUDS demand" if they were implemented as multiple localized systems throughout the city. This suggests a preference for large-scale measures. Additionally, there was widespread distress regarding the "risks to conventional drainage system performance" as the LWU's responsibilities for the city's urban drainage might be compromised:

> "If the construction, design, operation and maintenance of the drainage system of the city of Bogotá is LWU's responsibility, the LWU is also responsible for defining which of the technical alternatives are the ones that best fit a specific need. (…) SUDS in parallel must compete with other technical alternatives to solve the problem identified. This means that it is not placing

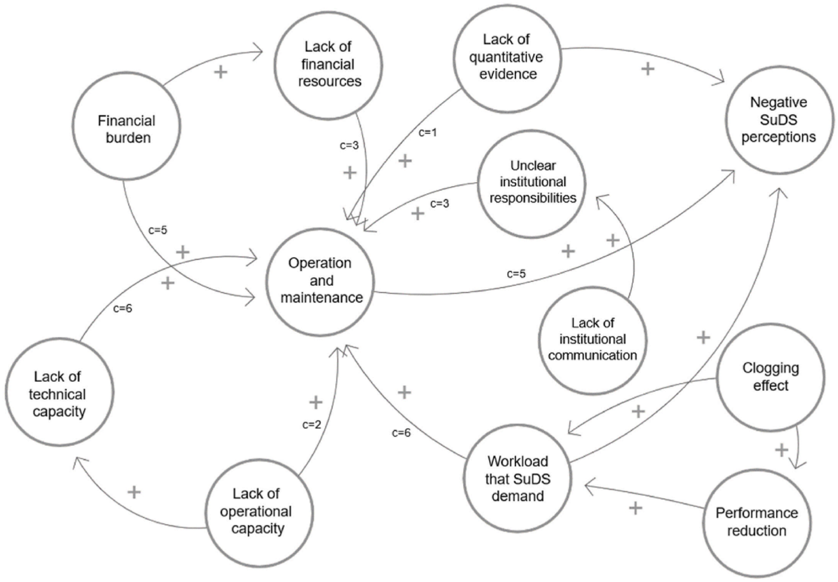

Fig. 4. "Operation and maintenance" barrier from the public sector's viewpoint.

SUDS for no reason, but rather a technical, operational, economic, social, and environmental evaluation should be made" (PU1).

LSE's and UDI's participants agreed that the LWU is reluctant toward SUDS due to O&M concerns, which have intensified institutional/organizational barriers such as "lack of institutional coordination/communication," "unclear institutional responsibilities," and "position of power of the water utility." For this reason, participant PU3 claimed the urgency of developing pilot projects: "until we implement SUDS, we will not know how they work or what their real maintenance costs are."

The second most frequent barrier derived from public sector participants' references was "diverse interpretations of the SUDS concept." From the general analysis, 12 of the 15 codings linked to this barrier were made by LWU participants. They referred to dry reservoirs, streams, and even a river (Río Tunjuelo) as if they were SUDS (PU1, PU2), presumably because they are part of the stormwater management infrastructure within the built environment of Bogotá. Conceptual divergences may have implications in knowledge dissemination among residents or other institutions, as well as in increasing support for SUWM strategies [47]. Therefore, a consensus is relevant in either a top-down or bottom-up approach.

Institutional/organizational barriers were those with the second highest presence in the analysis of public sector representatives' data (c = 35). "Responsibility vs. authority dilemma" and "position of power of the water utility" were the hindrances with the highest number of codings, followed by "unclear institutional responsibilities" and "lack of institutional coordination/communication." These barriers suggest self-awareness of internal and inter-departmental shortcomings, which, in the best cases, allows timely solutions to encourage SUDS uptake.

On the other hand, it was noteworthy that the two most relevant cultural/behavioral barriers across the public sector were "silo mentality" and "uncivil behaviors," expressed in relation to different actors. For instance, the "silo mentality" barrier was elucidated in quotations where participants expressed their individual preferences for large SUDS (PU1), the lack of trust in community engagement (PU3), and the disciplinary boundaries of urban planners, environmental engineers, and drainage professionals when designing SUDS (PU4). Conversely, the "uncivil behaviors" barrier was a concern only regarding the attitudes of some citizens, e.g., vandalism and littering, which discourage the promotion of SUDS in public spaces. In fact, community members (C4, C11, C13) mentioned that poor solid waste disposal by some neighbors had led to the clogging of stormwater inlets, causing drainage problems during the rainy season.

Financial barriers can be portrayed as a "lack of financial resources" considering SUDS construction or as a "financial burden" regarding O&M. One of the most striking barriers in this category was the "increase in water tariffs." The rationale behind this is that RWHS intensification could result in lower drinking water consumption, and therefore, the LWU would be forced to increase rates. This hindrance highlights the "position of power of the water utility," another barrier mentioned by participants from the other inquired sectors, excluding community members.

Urban barriers (c = 7) outweighed political barriers (c = 3), mainly due to "private land ownership" issues. According to the PU4 participant, about 84% of the space in Bogotá belongs to private-land use. Participant PU2 added that "if some private-land users do not advocate SUDS implementation, the initiative will not develop as it should." Therefore, it is essential to promote suitable SUDS typologies for these urban conditions.

4.1.4. Perceived barriers by urban developers

Institutional/organizational barriers were the most relevant during the analysis of urban developers' data (c = 27). Participants exposed past problems with the implementation of IB, IT, and TP due to "unclear institutional responsibilities" and "inflexible and conflicting rules". The "position of power of the water utility" barrier was also mentioned in the context of Bogotá and other Colombian cities, aggravated by the "lack of design standards and guidance" and the "lack of supportive policy and legal framework". To explain this, participant UD2 commented that some water utilities are not willing to receive SUWM systems. Despite being successful in one city, in another "you have to start over from scratch because the authorities are different." This has triggered feelings of frustration and disempowerment. Furthermore, it is worth noting that the aforementioned institutional/organizational barriers may impact housing projects' feasibility. For instance, if the SUDS design is not approved despite presenting the corresponding technical support, the companies are forced to adopt conventional strategies (UD4, UD7).

On the other hand, as well as for the public sector, O&M was the most commented technical barrier by urban developers, accounting for 14 codings. This barrier was linked to four more barriers, namely, "unclear institutional responsibilities" (UD1, UD3, UD7), "lack of supportive policy and legal framework" (UD3, UD7), "lack of technical capacity" (UD7), and "lack of operational capacity" (UD7). These relationships are shown in Fig. 5; examples of the empirical evidence can be found in Supplementary material, Table B2.

According to the co-occurrence analysis, the "unclear institutional responsibilities" barrier significantly affects O&M management. Developers addressed this relationship by referring to SUDS projects that, because of their obligations to the city, must be implemented in the public space. The long-term commitment generated by O&M raised feelings of rejection:

> "When the project or building is ours, in those cases we are interested in doing the operation and maintenance (…) But in urbanisms, no, we are not interested in staying to operate" (UD8).

Additionally, it is worth highlighting that the two technical barriers linked to O&M, i.e., "lack of operational capacity" and "lack of technical capacity," were commented only referring to the LWU capabilities:

> "They [LWU] do not maintain and operate the main ones, say, an open or concrete-lined channel or the pipes itself … We find operation and maintenance problems every day. Since these systems [SUDS], which, in quotes, are a little more specialized and with a little more delicate maintenance, we have always found resistance on this issue" (UD8).

Furthermore, although financial barriers ranked third in the overall analysis by category, the second most commented barrier from the urban developers' viewpoint was the financial burden that SUDS represent. As their current business focus, all companies referred to Housing of Social Interest (VIS, for its acronym in Spanish), a type of real estate project with a maximum sale value of 135 monthly legal minimum wages [97]. According to the questioned participants, this price restricts construction budgets, leaving little room for novel strategies such as SUDS. For instance, participant UD3 explained that implementation of RWHS is not feasible because "the price of water in Colombia is very cheap," so it is difficult to make a profit with water storage techniques.

Surprisingly, there were no references to urban form barriers. This may be related to the interest and conviction shown by the three companies, for which the implementation of SUDS has been an opportunity to develop sustainable projects and strategies, as will be addressed in Section 4.2.4. Political barriers were also irrelevant for urban developers, presumably due to the little interaction with political actors during project planning.

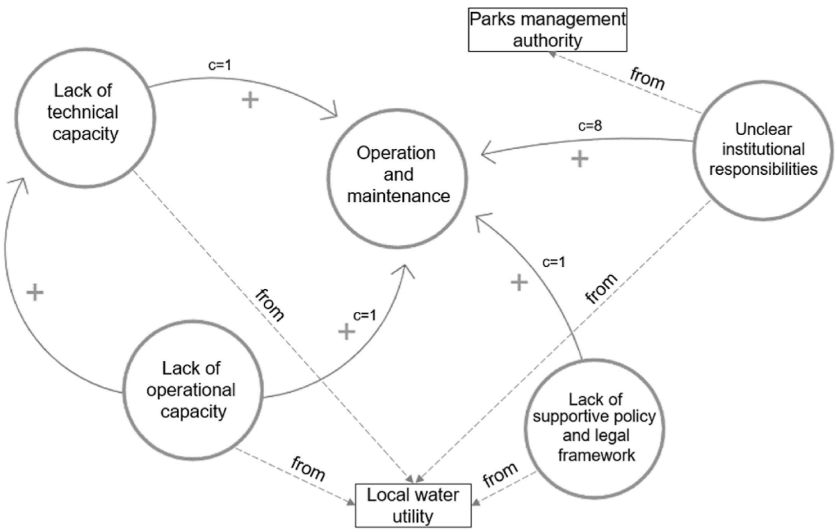

Fig. 5. "Operation and maintenance" barrier from urban developers' viewpoint.

4.2. Analysis of perceived benefits

The inductive–deductive coding process yielded 34 benefits linked to 104 codings, and identification was enabled using a previously developed code book derived from the literature (Table 2). Benefits not initially included in the codebook ($n = 13$) included "compensation of green area debt," "corporate image enhancement," "delaying water supply network expansion," "flexibility for repair and maintenance work," "hedonic housing prices," "improvement of customer's quality of life," "pipe diameter optimization," "promotion of urban farm projects," "protection of endangered vegetative species," "reduction of imperviousness," "reduction of the social gap," "social responsibility," and "water pumping system optimization." This demonstrates the enormous environmental, social, and market-related potential that SUWM strategies such as SUDS provide to various segments of society. Table 5 shows the classification and distribution of all benefits found in this study based on the sectors investigated.

The participants from the public sector, urban developers, and community members had a homogeneous number of benefit-related codings. The number of references made by the private non-profit organization is reduced, presumably because of the number of participants and their role as consultants, describing the general benefits identified of their work with urban developers. The analysis of the perceived benefits according to each sector will be analyzed in the following sections.

4.2.1. Perceived benefits by community members

Three typologies that best adapt to the built environment on private land were pre-selected for evaluation by the community participants: RWHS, BRS, and GR. Of 14 benefits distributed in 33 mentions, the "use of harvested water in secondary uses" (c = 11) stood out. Alternative uses comprised cleaning purposes (C3, C8, C9, C11), toilet flushing (C3, C7, C11), dish washing (C7), gardening (C3, C4, C6), and urban farm irrigation (C8, C9). Moreover, participant C12 highlighted the relevance of the "decentralized water supply" benefit when there are unexpected water cuts.

In most cases, "flood risk mitigation" (c = 4) was mentioned as a consequence of the use of harvested rainwater in daily tasks. According to the participants, the less stormwater that circulates in the streets, the lower the risk of flooding. It is worth noting that the community members consulted in the present study belong to a waterlogging- and flood-prone area due to the low-land nature of the

Table 5
Summary of perceived benefits of SUDS implementation.

Perceived benefits	C ($np = 13$)	PR ($np = 2$)	PU ($np = 5$)	UD ($np = 8$)	ec
Air quality enhancement	–	–	1	–	1
Amenity	4	–	2	1	7
Aquifer recharge	–	–	–	3	3
Biodiversity augmentation	1	–	1	–	2
Climate change adaptation and mitigation	–	–	1	–	1
Compensation of green area debt	–	–	1	–	1
Corporate image enhancement	–	–	–	1	1
Decentralized water supply	1	–	–	–	1
Delaying water supply network expansion	–	–	1	–	1
Flexibility for repair and maintenance work	–	–	1	–	1
Flood risk mitigation	4	–	5	1	10
Health and well-being improvement	1	1	–	–	2
Heat resilience	–	–	2	1	3
Hedonic housing prices	–	–	1	–	1
Improvement of customer's quality of life	–	–	–	1	1
Noise reduction	–	–	2	–	2
Peak flow reduction	–	–	2	1	3
Pipe diameter optimization	–	–	–	5	5
Promotion of ecosystem services	1	–	–	–	1
Promotion of environmental awareness	2	–	2	3	7
Promotion of multifunctional spaces	2	1	–	1	4
Promotion of urban farm projects	1	–	–	–	1
Protection of endangered vegetative species	1	–	–	–	1
Recreation opportunities	–	–	–	1	1
Reduction in water treatment costs	–	–	1	–	1
Reduction of imperviousness	–	–	2	2	4
Reduction of the social gap	1	–	–	–	1
Runoff volume control	2	1	5	1	9
Social responsibility	–	–	–	1	1
Stormwater management	–	–	–	2	2
Tax reduction	–	–	–	1	1
Use of harvested water in secondary uses	11	–	–	7	18
Water pumping system optimization	–	–	–	1	1
Water quality enhancement	1	–	4	–	5
Total number of codings	33	3	34	34	104

C: community members; PR: private non-profit organization; PU: public sector; UD: urban developers; np: number of participants; ec: excerpt counts.

site [65] and the insufficient capacity of the local drainage system [68]. Therefore, it would be interesting to quantify the impact of RWHS on reducing flood extents and depths.

"Amenity" (c = 4), "promotion of multifunctional spaces" (c = 2), "runoff volume control" (c = 2), and "promotion of environmental awareness" (c = 2) followed as the most mentioned benefits. They all provide social, economic, and environmental benefits, reflecting the ability of SUDS strategies to provide attractive spaces for community members. Moreover, one of the most striking benefits, which was not mentioned by participants from other sectors, was the "reduction of the social gap." According to participant C13, the implementation of SUDS provides an opportunity for low-income sectors to enjoy pleasant environments:

> "I am sorry for what I'm going to say, but that the *** that comes from the city not only arrives to the southern part and then, those of us living here, have to put up with it. Quite the opposite, that [our neighborhood] also looks good, looks nice" (C13).

Most of the benefits with a single mention, i.e., "biodiversity augmentation," "health and well-being improvement," "promotion of ecosystem services," "protection of endangered vegetative species," and "reduction of the social gap," were remarked by the same participant, C13, an environmental engineering student. The C13 participant showed enthusiasm about "supporting [environmental strategies] and working in the territory," which can be key for developing community-led projects.

Examples of quotations of all mentioned benefits by the community members can be found in Supplementary material, Table C1.

4.2.2. Perceived benefits by a private non-profit organization

Three benefits were mentioned by the CGBC representatives, i.e., "promotion of multifunctional spaces" (PR2), "runoff volume control" (PR1), and "health and well-being improvement" (PR2). Note that these benefits arose from their perspective as consultants when housing companies apply for GBC. In fact, some urban developers who participated in the present study illustrated their own examples of these benefits. For instance, participant UD6 highlighted the benefits of GR implementation on walkable roofs since these places "have become passive recreation areas for the inhabitants." Additionally, participant UD4 commented on some advantages of RWHS in the company building, such as providing an alternative water supply for cleaning tasks and thus reducing drinking water consumption.

The key role that private non-profit organizations supporting sustainable practices play in promoting the benefits of SUWM was evidenced in this study. For instance, one of CGBC's strategic lines to strengthen sustainable construction practices is knowledge dissemination through open-access training and market mobilization. In this sense, the CGBC offers valuable tools for water demand assessment, performing water balance models to replicate natural flows, and providing guidance for implementing water-saving devices (PR1, PR2). Moreover, the CBGC is consulted for urban policy-making at the regional and national levels in order to develop long-term strategies within the framework of the SDGs.

4.2.3. Perceived benefits by public sector representatives

Public sector representatives referred to 17 benefits through 34 codings. The most prominent benefits include "runoff volume control" (c = 5), "flood risk mitigation" (c = 5), and "water quality enhancement" (c = 4). This suggests consensus within the public sector about the quality and quantity control capabilities of SUDS. Furthermore, participant PU4 (renowned local SUDS champion) highlighted the importance of quantifying benefits such as "heat resilience," "amenity," and "improving health and well-being" within the cost-benefit analysis to increase civil engineers' interest: "the conclusion [from the scientific literature on O&M] is that yes, they are expensive, but because all the benefits of SUDS implementation are not quantified."

Additional benefits mentioned by the public sector participants are narrowly related to ecosystem services, i.e., "amenity," "heat resilience," "peak flow reduction," "biodiversity augmentation," "air quality enhancement," and "climate change adaptation and mitigation." This demonstrates the great environmental and social scope of SUWM strategies such as SUDS. On the other hand, several benefits are technical in nature, aligned with the professional background of some participants, and have been poorly explored within the SUDS literature. For instance, participant PU2 mentioned that large-scale SUDS implementation could support the "delay of water supply network expansion": "if this becomes a very massive thing where drinking water consumption is reduced (…) there will be benefits such as delaying investments for projects to expand supply systems." PU2 also referred to the "flexibility for repair and maintenance work" that SUDS represent compared with conventional drainage systems, alluding to issues of urban densification and traffic congestion:

> "In a network that is getting older and older and, in a city, as dense and complex as Bogotá, well, thinking of changing a pipe of, I don't know, 800 mm and changing it to 1200 mm, (…) each time a different calculation is made, it is simply unfeasible, not even from an economic point of view, but from the point of view of the city, given the traffic jam that this type of work often generates." (PU2).

In addition, participant PU4 mentioned the "compensation of green area debt" benefit, which arose from a public policy created by the LSE and UDI to encourage the implementation of SUDS in road renovation projects. PU4 also commented on the hedonic prices in the real estate market, arguing that "landscape benefits can be seen as a potential benefit for the implementation of SUDS in private properties."

Examples of quotations of all benefits mentioned by public sector representatives can be found in Supplementary material, Table C2.

4.2.4. Perceived benefits by urban developers

Urban developers referred to 18 benefits through 34 codings, highlighting the "use of harvested water in secondary uses" (c = 7). Alternative uses included maintenance activities (UD2 and UD3), gardening (UD2, UD5, UD6, and UD7), common areas cleaning (UD4 and UD6), and toilet flushing (UD4). This benefit, along with "stormwater management" and "runoff volume control," was identified as decisive in the process of certification of sustainable constructions (UD2, UD4, and UD6). This reflects the importance of understanding the needs of all types of actors involved in SUWM because, although the "use of harvested water in secondary uses" was also the benefit most mentioned by community members, the motivations were different.

Benefits such as "pipe diameter optimization" (c = 5) and "water pumping system optimization" (c = 1) were primarily associated with economic gains because SUDS should function as complementary components to the traditional drainage system. Despite having completed the corresponding technical study, participants (UD3, UD7) stated that obstacles such as the "lack of design standards and guidance" and the "position of power of the water utility" have reduced these opportunities. Participant UD4 added that "if one goes over budget, it is absolutely impossible to compete." These interests, including "corporate image enhancement" (c = 1), are underexplored in the literature and are key to increasing SUDS uptake in all relevant sectors.

Conversely, "amenity," "flood risk mitigation," "heat resilience," "peak flow reduction," "promotion of multifunctional spaces," "recreation opportunities," and "runoff volume control" were benefits with a social component in the interviewees' speech, evoking mainly the improvement of the citizens' welfare. In fact, participant UD5 mentioned "improvement of customer's quality of life" as a key benefit of SUDS implementation in their housing projects. This highlights the ability of SUDS to create end-to-end solutions that transcend the urban developer's profits.

Examples of quotations of all benefits mentioned by public sector representatives can be found in Supplementary material, Table C3.

5. Discussion

This work is consistent with the efforts of several authors exploring comprehensive management of natural hazards such as urban flooding [98], aiming to facilitate public participation [99,100], implement efficient non-structural strategies [101,102], create flood-resilient communities [103], and raise levels of acceptance of new measures [71,104,105]. Nevertheless, the lack of research addressing the challenges of SUWM in the context of developing countries [18,106] was confirmed.

This study introduces three main novelties. The first is sectoral representativeness, as evidenced in the investigation of four key actors: the public sector, urban developers, a private non-profit organization in the field of sustainable construction, and community members living in flood-prone areas. The second is an analysis in the context of Bogotá, the capital city of Colombia (a developing country), offering sound evidence for regions sharing socio-geographical similarities. Finally, the systematic identification and evaluation of factors that promote or hinder the transition to SUWM.

5.1. Perceived barriers

The present analysis revealed that technical barriers still have great relevance in the adoption of SUDS, mainly from the perspective of the public sector and urban developers. This contrasts with previous research in developed countries that claims that major barriers impeding SUDS uptake are more socio-political rather than technical [19,23,107,108]. Nonetheless, institutional/organizational barriers played an important role in understanding inter- and cross-sectoral dynamics, so hindrances in other areas could be more easily addressed. It should be noted that all the public authorities investigated in the present study were aware of their institutional shortcomings, either at the individual or inter-departmental level. A dialogue with urban developers, for whom institutional/organizational barriers were the most significant, could improve the capabilities of both sectors in the transition to SUWM.

The "Operation and maintenance (O&M)" technical barrier, was mostly referenced by the above-mentioned sectors, in line with the findings of earlier studies. For instance, Nguyen et al. [109] noted that O&M of urban flood adaptation measures may require more expertise and skills than conventional drainage systems. Added to this, the maintenance costs of GI and BGI raised the concerns of designers and managers in Nairobi, Kenya [35]. The network analysis in this study elucidated direct links between O&M and important technical, financial, and institutional/organizational constraints, which are also covered in previous research [17,35,48]. This emphasizes the significance of multi-stakeholder partnerships in supporting the transition to SUWM to ensure successful long-term implementation. Furthermore, in cities where SUWM interest is recent, using low-maintenance techniques can increase buy-in and uptake [36,109].

This study confirmed the relevance of exploring cultural/behavioral barriers highlighted in former research [49,54], which, in the general analysis, were above financial constraints. Note that the recognition of these types of barriers is not straightforward since they are derived from intangible factors such as mindset, fear, attitudes, and perceptions [48]. Herein lies the importance of their analysis since they can boost other types of hindrances. For instance, "path dependency," which includes vested interests in grey infrastructure [48,54], may be related to the risk aversion barrier described by Sarabi et al. [96], as public and private sectors are concerned with financial losses. In turn, "silo mentality" shrinks efforts to increase knowledge [47] and joint learning [110]. Furthermore, the "uncivil behaviors" barrier, mentioned mainly by the public sector in relation to citizens' attitudes, can reduce SUDS overall performance [111]. This barrier was identified as the main challenge for developing sustainable practices by some community and public sector participants in a previous study [83].

On the other hand, financial hindrances have been identified by several authors as relevant in the implementation of SUWM strategies [51,110]. Although, in this analysis, this category was surpassed by technical, institutional/organizational, and cultural/behavioral barriers, all participating sectors mentioned either the lack of financial resources (community and the public sector) or the financial burden (the public sector, private non-profit organization, and urban developers) that SUDS represent. In the latter case, the conception that water supply is inexpensive in Colombia prevents the promotion of typologies such as RWHS due to low ROI. This opinion contrasts with the willingness of a low-income community surveyed in Ciudad Verde (neighboring area of Bosa) to resort to water-saving practices due to high drinking water and sewage service costs [112]. This highlights the significance of investigating different perspectives on urban water management, whether to promote the co-creation of solutions or implement government-led initiatives.

Community members inquired in this research highlighted the “lack of community ownership” followed by the “lack of general knowledge” as major barriers hindering further SUDS implementation. Similar results were found in a study conducted in the Gregório stream catchment, São Paulo, Brazil, where local residents ranked the lack of community engagement as the most important barrier in adopting SUWM [113]. According to Thorne et al. [41], improving access to information might increase community ownership and buy-in. Therefore, campaigns to raise awareness of both the growing problem of urban flooding and the opportunities provided by multifunctional solutions such as SUDS can aid in the development of community-led initiatives.

The development of a code book to perform the inductive–deductive analysis revealed some peculiarities. To the best of the authors’ knowledge, the barrier “increase in water tariffs” commented by participant PU2 (LWU specialist) has not been thoroughly investigated. In turn, it is directly related to the “position of power of the water utility” barrier, which ranked fifth in the overall study but has received little attention in the literature. Since water authorities are often the most powerful actors and they tend to favor specific and mono-functional objectives [114], interdisciplinary initiatives might enable greater leadership. Another barrier that lacks research support is the creation of indoor humidity conditions mentioned by participant C4, alluding to the operation of RWHS. Contrary to this, members of the Bon Pastor neighborhood in Spain indicated a reduction in humidity problems due to an SUDS scheme in public areas composed of hollowed gardens, permeable pavements, bioretention strips, and new stormwater collectors [83]. Both are community perceptions worth evaluating to improve SUDS uptake.

Alternatively, technical barriers such as “clogging effect,” “performance reduction,” and “risks to conventional drainage system performance” have been widely investigated through hydraulic, hydrological, and optimization models [115–118]. However, there is a lack of evidence from participatory studies. All citations referring to these barriers (a total of 18) stemmed from perceptions and misconceptions from the public sector participants and urban developers. This may be linked to other technical barriers such as “lack of quantitative evidence/performance information” and “lack of local experience/benchmarks.” However, participant UD3 mentioned having performed technical tests in the company's Research and Development division. Unfortunately, the tested PP did not produce the expected results in terms of visual appearance and maintenance. This highlights the critical role that knowledge supported by technical evidence plays in increasing the adoption of SUWM strategies.

The data collection and data analysis methods used in this study revealed that participants’ opinions are enriched by their exposure to a given topic and the role they play. For instance, the analysis of perceived barriers resulted in 175 mentions made by five public sector representatives, whereas the 13 surveyed community members made 34 mentions. The most obvious reason for this disparity is the lack of SUDS knowledge. However, this also exposes the strong top-down approach in both stormwater management and urban planning decision-making. Previous researchers called for a balance between technocratic and bottom-up approaches [21,51]. Nonetheless, it is important to consider the influence of the local institutional and economic context [87,119,120].

5.2. Perceived benefits

The general analysis of benefits perceived by the four sectors investigated evidenced the narrow link to ecosystem services (ES) in all categories, i.e., provisioning, regulating, supporting, and cultural [121]. Connop et al. [76] indicate that SUDS allow the leveraging of additional ES, whereas Alves et al. [122] and Bark and Acreman [107] agree that ES enhances the potential and acceptance of SUDS. In any case, economic and social benefits found in this study, such as “hedonic housing prices,” “promotion of environmental awareness,” and “reduction of social gap,” highlighted the wide scope and impact of SUDS in the urban dynamics.

The present analysis demonstrated the importance of including relevant sectors of SUDS management at the private level, such as urban developers, who mentioned benefits not previously discussed in the literature, i.e., “improvement of customers’ quality of life” and “corporate image enhancement.” The latter may be related to marketing, one of the facilitators for the application of LID [37] and NbS [47]. Others, such as “pipe diameter optimization” and “water pumping system optimization,” reflect the relevance of considering economic factors to improve the feasibility of projects promoting SUWM strategies. On the other hand, benefits mentioned by public sector representatives such as “compensation of green area debt,” “flexibility for repair and maintenance work,” “delaying of water supply network expansion,” and “reduction in water treatment costs,” revealed how SUDS, in addition to providing multiple benefits, may assist public management and policy-making. Identifying and quantifying all possible benefits and co-benefits allows leveraging public investment [36,123] and reducing financial constraints [109]. Future research might be valuable based on the local socio-economic context of Bogotá.

Furthermore, previous studies have emphasized the relevance of adopting bottom-up approaches in urban water management when top-down structures have proven to be ineffective [17,51]. For this reason, the study of perceived benefits by citizens is key to achieving successful community participation. Even though time constraints did not allow for a representative sample of this sector and definitive conclusions cannot be drawn, participants cited a wide range of social, economic, and environmental benefits worth evaluating. Moreover, Bogotá has great potential for implementing property-level strategies such as RWHS and GR, considering that 84% of the city's land is privately owned (PU4). In this sense, knowledge dissemination and benefit awareness initiatives, in addition to incentive-based policies [124], are key to encouraging SUWM.

Although delving into solutions to overcome barriers hindering SUDS implementation was beyond the scope of this study, several authors have highlighted some of the presented benefits as drivers, facilitators, or enablers to foster wider adoption of SUDS

[23,36,37,47]. In addition, according to Gashu and Gebre-Egziabher [49], identifying barriers and working to overcome them facilitate GI planning and development. Thus, this study offers 73 key starting points (39 barriers and 34 benefits) to unravel the complex dynamics of efficient urban water planning and sustainable hydro-meteorological risk management. This task is eased by an understanding of barriers and benefits relationships, also evidenced in this study and previous research [23,47,53,96].

6. Conclusions

This study aimed to identify and assess the factors that promote and hinder the transition to SUWM by investigating the perceived barriers to and benefits of SUDS adoption from the viewpoints of four key urban water sectors in Bogotá, Colombia. The main findings include the following: (i) multi-sector analysis provides valuable insights for understanding the local-context strengths and constraints in alternative urban water management and city planning; (ii) technical barriers still have a great impact on SUDS uptake, contrasting with some studies from developed countries where socio-political barriers prevail; (iii) institutional/organizational and cultural/behavioral barriers may surpass financial constraints; (iv) there is a strong relationship between SUDS benefits and ecosystem services even though some economic, social, and environmental advantages are beyond this categorization; and (v) there are direct links between barriers, benefits, and actors that should be considered in the comprehensive planning of stormwater management solutions.

In line with the research gaps we sought to address, there are two main limitations for this study to be conclusive. Although the number of participants is reduced, findings derived from the multisectoral analysis are more exploratory [92], offer representativeness in the local context [125], and portray the diversity of views [83] on sustainable strategies. Furthermore, lessons learned from a single-case study are informative and insightful [126], laying the basis for future research. The other limitation refers to the data collection method used in the community sector. Initially, the interaction was devised as FGD, but because of the COVID-19 pandemic issues, it had to be modified, which may have influenced the scope of participating members. Nonetheless, questionnaires with open-ended questions facilitated the creation of a more fluent communication channel and the manifestation of preferences and perceptions.

Our findings stress the importance of future research on multiple areas: (i) an economic assessment of SUDS benefits based on this study to leverage interest and help overcome some of the presented barriers; (ii) the exploration of other demographic and socio-economic contexts, whether local, national, or Latin American, to contribute to the regional and international debate on sustainable urban planning; and (iii) the development of participatory spatial-hydraulic modeling-based investigations to assess SUDS impact on local FRM.

This research does not seek to draw universally applicable assertions or definitive conclusions for the city of Bogotá. The results of this study emphasize the importance of employing interdisciplinary approaches to achieve an efficient transition to SUWM and provide a sound basis for such analysis in cities with comparable features in terms of urban planning and growth, stormwater management, and socio-economic-institutional dynamics. Moreover, acknowledging the above-mentioned limitations and future work scope, the adopted methodology proved to be flexible and effective for analyzing multisectoral opinions, reducing the inherent biases of qualitative research, and can be easily exported to other contexts worldwide. We hope that our study spurs greater interest in all relevant sectors, encourages cross-sector partnerships, and that our findings can be useful in sustainable flood risk management.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2023.103621.

References

[1] S.M. Charlesworth, A review of the adaptation and mitigation of global climate change using sustainable drainage in cities, J. Water Clim. Chang. 1 (2010) 165–180, https://doi.org/10.2166/wcc.2010.035.

[2] Q. Zhou, T.E. Panduro, B.J. Thorsen, K. Arnbjerg-Nielsen, Adaption to extreme rainfall with open urban drainage system: an integrated hydrological cost-benefit analysis, Environ. Manag. 51 (2013) 586–601, https://doi.org/10.1007/s00267-012-0010-8.

[3] K. Abass, D. Buor, K. Afriyie, G. Dumedah, A.Y. Segbefi, L. Guodaar, E.K. Garsonu, S. Adu-Gyamfi, D. Forkuor, A. Ofosu, A. Mohammed, R.M. Gyasi, Urban sprawl and green space depletion: implications for flood incidence in Kumasi, Ghana, Int. J. Disaster Risk Reduc. 51 (2020) 101915, https://doi.org/10.1016/j.ijdrr.2020.101915.

[4] A. Pathirana, H.B. Denekew, W. Veerbeek, C. Zevenbergen, A.T. Banda, Impact of urban growth-driven landuse change on microclimate and extreme precipitation - a sensitivity study, Atmos. Res. 138 (2014) 59–72, https://doi.org/10.1016/j.atmosres.2013.10.005.

[5] E. Arnone, D. Pumo, A. Francipane, G. La Loggia, L.V. Noto, The role of urban growth, climate change, and their interplay in altering runoff extremes, Hydrol. Process. 32 (2018) 1755–1770, https://doi.org/10.1002/hyp.13141.
[6] K. Hussein, K. Alkaabi, D. Ghebreyesus, M.U. Liaqat, H.O. Sharif, Land use/land cover change along the Eastern Coast of the UAE and its impact on flooding risk, Geomatics, Nat. Hazards Risk 11 (2020) 112–130, https://doi.org/10.1080/19475705.2019.1707718.
[7] M. Saber, K.I. Abdrabo, O.M. Habiba, S.A. Kantosh, T. Sumi, Impacts of triple factors on flash flood vulnerability in Egypt: urban growth, extreme climate, and mismanagement, Geosci. 10 (2020), https://doi.org/10.3390/geosciences10010024.
[8] J. Ran, Z. Nedovic-Budic, Integrating spatial planning and flood risk management: a new conceptual framework for the spatially integrated policy infrastructure, Comput. Environ. Urban Syst. 57 (2016) 68–79, https://doi.org/10.1016/j.compenvurbsys.2016.01.008.
[9] A.K. Jha, R. Bloch, J. Lamond, Cities and flooding: a guide to integrated urban flood risk management for the 21st century, 1. The World Bank, Washington, DC. 8 (1) (2012) ASCE)1084-0699 2003, 10.1061/.
[10] J.Á. Díaz, Análisis De Aspectos Que Incrementan El Riesgo De Inundaciones En Colombia, Luna Azul, 2013, pp. 219–238, https://doi.org/10.17151/luaz.2013.37.13.
[11] UNDESA, World Urbanization Prospects, The 2018 Revision, New York, 2019.
[12] K. Park, M.H. Lee, The development and application of the urban flood risk assessment model for reflecting upon urban planning elements, Water (Switzerland) 11 (2019) 1–18, https://doi.org/10.3390/w11050920.
[13] M.J. Hammond, A.S. Chen, S. Djordjević, D. Butler, O. Mark, Urban flood impact assessment: a state-of-the-art review, Urban Water J. 12 (2015) 14–29, https://doi.org/10.1080/1573062X.2013.857421.
[14] G. Hilly, Z. Vojinovic, S. Weesakul, A. Sanchez, D.N. Hoang, S. Djordjevic, A.S. Chen, B. Evans, Methodological framework for analysing cascading effects fromflood events: the case of Sukhumvit area, Bangkok, Thailand, Water (Switzerland) 10 (2018) 7–11, https://doi.org/10.3390/w10010081.
[15] P. Kumar, S.E. Debele, J. Sahani, L. Aragão, F. Barisani, B. Basu, E. Bucchignani, N. Charizopoulos, S. Di Sabatino, A. Domeneghetti, A.S. Edo, L. Finér, G. Gallotti, S. Juch, L.S. Leo, M. Loupis, S.B. Mickovski, D. Panga, I. Pavlova, F. Pilla, A.L. Prats, F.G. Renaud, M. Rutzinger, A.S. Basu, M.A.R. Shah, K. Soini, M. Stefanopoulou, E. Toth, L. Ukonmaanaho, S. Vranic, T. Zieher, Towards an operationalisation of nature-based solutions for natural hazards, Sci. Total Environ. 731 (2020) 138855, https://doi.org/10.1016/j.scitotenv.2020.138855.
[16] S. Mori, T. Pacetti, L. Brandimarte, R. Santolini, E. Caporali, A methodology for assessing spatio-temporal dynamics of flood regulating services, Ecol. Indicat. 129 (2021) 107963, https://doi.org/10.1016/j.ecolind.2021.107963.
[17] P. Mguni, L. Herslund, M.B. Jensen, Green infrastructure for flood-risk management in Dar es Salaam and Copenhagen: exploring the potential for transitions towards sustainable urban water management, Water Pol. 17 (2015) 126–142, https://doi.org/10.2166/wp.2014.047.
[18] V. Pappalardo, D. La Rosa, Policies for sustainable drainage systems in urban contexts within performance-based planning approaches, Sustain. Cities Soc. 52 (2020) 101830, https://doi.org/10.1016/j.scs.2019.101830.
[19] M. Gimenez-Maranges, V. Pappalardo, D. La Rosa, J. Breuste, A. Hof, The transition to adaptive storm-water management: learning from existing experiences in Italy and Southern France, Sustain. Cities Soc. 55 (2020) 102061, https://doi.org/10.1016/j.scs.2020.102061.
[20] S.G. Taji, D.G. Regulwar, LID coupled design of drainage model using GIS and SWMM, ISH J. Hydraul. Eng. 5010 (2019), https://doi.org/10.1080/09715010.2019.1660919.
[21] L. Liu, M.B. Jensen, Green infrastructure for sustainable urban water management: practices of five forerunner cities, Cities 74 (2018) 126–133, https://doi.org/10.1016/j.cities.2017.11.013.
[22] Z.T. Miao, M. Han, S. Hashemi, The effect of successive low-impact development rainwater systems on peak flow reduction in residential areas of Shizhuang, China, Environ. Earth Sci. 78 (2019) 1–12, https://doi.org/10.1007/s12665-018-8016-z.
[23] M. Wihlborg, J. Sörensen, J. Alkan Olsson, Assessment of barriers and drivers for implementation of blue-green solutions in Swedish municipalities, J. Environ. Manag. 233 (2019) 706–718, https://doi.org/10.1016/j.jenvman.2018.12.018.
[24] B. Woods, S. Wilson, H. Udale-Clarke, S. Illman, T. Scott, R. Ashley, R. Kellagher, The SuDS Manual, CIRIA, London, 2015. http://www.persona.uk.com/A47postwick/deposit-docs/DD-181.pdf.
[25] City of Edmonton, Low Impact Development Best Management Practices Design Guide Edition 1.1 (2014).
[26] S.L. Jiménez, J.A. Martínez, A.F. Muñoz, J.P. Quijano, J.P. Rodríguez, L.A. Camacho, M. Díaz-Granados, A multicriteria planning framework to locate and select sustainable urban drainage systems (SUDS) in consolidated urban areas, Sustain. Times 11 (2019), https://doi.org/10.3390/su11082312.
[27] C. Damodaram, M.H. Giacomoni, C. Prakash Khedun, H. Holmes, A. Ryan, W. Saour, E.M. Zechman, Simulation of combined best management practices and low impact development for sustainable stormwater management, J. Am. Water Resour. Assoc. 46 (2010) 907–918, https://doi.org/10.1111/j.1752-1688.2010.00462.x.
[28] H. Jia, Y. Lu, S.L. Yu, Y. Chen, Planning of LID-BMPs for urban runoff control: the case of Beijing Olympic Village, Separ. Purif. Technol. 84 (2012) 112–119, https://doi.org/10.1016/j.seppur.2011.04.026.
[29] A. Alves, A. Sanchez, B. Gersonius, Z. Vojinovic, A model-based framework for selection and development of multi-functional and adaptive strategies to cope with urban floods, Procedia Eng. 154 (2016) 877–884, https://doi.org/10.1016/j.proeng.2016.07.463.
[30] A.N. Majidi, Z. Vojinovic, A. Alves, S. Weesakul, A. Sanchez, F. Boogaard, J. Kluck, Planning nature-based solutions for urban flood reduction and thermal comfort enhancement, Sustain. Times 11 (2019), https://doi.org/10.3390/su11226361.
[31] A. Alves, J.P. Gómez, Z. Vojinovic, A. Sánchez, S. Weesakul, Combining co-benefits and stakeholders perceptions into green infrastructure selection for flood risk reduction, Environ. - MDPI. 5 (2018) 1–23, https://doi.org/10.3390/environments5020029.
[32] D. Johnson, S. Geisendorf, Are neighborhood-level SUDS worth it? An assessment of the economic value of sustainable urban drainage system scenarios using cost-benefit analyses, Ecol. Econ. 158 (2019) 194–205, https://doi.org/10.1016/j.ecolecon.2018.12.024.
[33] T.D. Fletcher, W. Shuster, W.F. Hunt, R. Ashley, D. Butler, S. Arthur, S. Trowsdale, S. Barraud, A. Semadeni-Davies, J.L. Bertrand-Krajewski, P.S. Mikkelsen, G. Rivard, M. Uhl, D. Dagenais, M. Viklander, L.I.D. Suds, BMPs, WSUD and more – the evolution and application of terminology surrounding urban drainage, Urban Water J. 12 (2015) 525–542, https://doi.org/10.1080/1573062X.2014.916314.
[34] N.A. Zakaria, A. Ab Ghani, R. Abdullah, L. Mohd Sidek, A. Ainan, Bio-ecological drainage system (BIOECODS) for water quantity and quality control, Int. J. River Basin Manag. 1 (2003) 237–251, https://doi.org/10.1080/15715124.2003.9635210.
[35] J. Mulligan, V. Bukachi, J.C. Clause, R. Jewell, F. Kirimi, C. Odbert, Hybrid infrastructures, hybrid governance: new evidence from Nairobi (Kenya) on green-blue-grey infrastructure in informal settlements: "Urban hydroclimatic risks in the 21st century: integrating engineering, natural, physical and social sciences to build, Anthropocene 29 (2020) 100227, https://doi.org/10.1016/j.ancene.2019.100227.
[36] L. Li, A.M. Collins, A. Cheshmehzangi, F.K.S. Chan, Identifying enablers and barriers to the implementation of the Green Infrastructure for urban flood management: a comparative analysis of the UK and China, Urban For. Urban Green. 54 (2020) 126770, https://doi.org/10.1016/j.ufug.2020.126770.
[37] J.H. Kim, H.Y. Kim, F. Demarie, Facilitators and barriers of applying low impact development practices in urban development, Water Resour. Manag. 31 (2017) 3795–3808, https://doi.org/10.1007/s11269-017-1707-5.
[38] T. Thaler, M.S. Attems, M. Bonnefond, D. Clarke, A. Gatien-Tournat, M. Gralepois, M. Fournier, C. Murphy, M. Rauter, M. Papathoma-Köhle, S. Servain, S. Fuchs, Drivers and barriers of adaptation initiatives – how societal transformation affects natural hazard management and risk mitigation in Europe, Sci. Total Environ. 650 (2019) 1073–1082, https://doi.org/10.1016/j.scitotenv.2018.08.306.
[39] G. Zhang, B.J. He, Towards green roof implementation: drivers, motivations, barriers and recommendations, Urban For. Urban Green. 58 (2021), https://doi.org/10.1016/j.ufug.2021.126992.
[40] R.R. Brown, M.A. Farrelly, Delivering sustainable urban water management: a review of the hurdles we face, Water Sci. Technol. 59 (2009) 839–846, https://doi.org/10.2166/wst.2009.028.
[41] C.R. Thorne, E.C. Lawson, C. Ozawa, S.L. Hamlin, L.A. Smith, Overcoming uncertainty and barriers to adoption of Blue-Green Infrastructure for urban flood risk management, J. Flood Risk Manag. 11 (2018) https://doi.org/10.1111/jfr3.12218, S960–S972.
[42] A.E. Barbosa, J.N. Fernandes, L.M. David, Key issues for sustainable urban stormwater management, Water Res. 46 (2012) 6787–6798, https://doi.org/10.1016/j.watres.2012.05.029.

[43] S.E. Sarabi, Q. Han, A.G.L. Romme, B. de Vries, L. Wendling, Key enablers of and barriers to the uptake and implementation of nature-based solutions in urban settings: a review, Resources 8 (2019), https://doi.org/10.3390/resources8030121.
[44] R. D'Ambrosio, A. Balbo, A. Longobardi, A. Rizzo, Re-think urban drainage following a SuDS retrofitting approach against urban flooding: a modelling investigation for an Italian case study, Urban For. Urban Green. 70 (2022) 127518, https://doi.org/10.1016/j.ufug.2022.127518.
[45] V. Venkataramanan, A.I. Packman, D.R. Peters, D. Lopez, D.J. McCuskey, R.I. McDonald, W.M. Miller, S.L. Young, A systematic review of the human health and social well-being outcomes of green infrastructure for stormwater and flood management, J. Environ. Manag. 246 (2019) 868–880, https://doi.org/10.1016/j.jenvman.2019.05.028.
[46] L. Chelleri, H.W. Kua, J.P.R. Sánchez, K. Md Nahiduzzaman, G. Thondhlana, Are people responsive to a more sustainable, decentralized, and user-driven management of urban metabolism? Sustain. Times 8 (2016) 1–12, https://doi.org/10.3390/su8030275.
[47] S. Han, C. Kuhlicke, Barriers and drivers for mainstreaming nature-based solutions for flood risks: the case of South Korea, Int. J. Disaster Risk Sci. 12 (2021) 661–672, https://doi.org/10.1007/s13753-021-00372-4.
[48] K.P. Dhakal, L.R. Chevalier, Managing urban stormwater for urban sustainability: barriers and policy solutions for green infrastructure application, J. Environ. Manag. 203 (2017) 171–181, https://doi.org/10.1016/j.jenvman.2017.07.065.
[49] K. Gashu, T. Gebre-Egziabher, Barriers to green infrastructure development and planning in two Ethiopian cities: bahir Dar and Hawassa, Urban Ecosyst. 22 (2019) 657–669, https://doi.org/10.1007/s11252-019-00852-y.
[50] J. Deely, S. Hynes, J. Barquín, D. Burgess, G. Finney, A. Silió, J.M. Álvarez-Martínez, D. Bailly, J. Ballé-Béganton, Barrier identification framework for the implementation of blue and green infrastructures, Land Use Pol. 99 (2020), https://doi.org/10.1016/j.landusepol.2020.105108.
[51] N. Drosou, R. Soetanto, F. Hermawan, K. Chmutina, L. Bosher, J.U.D. Hatmoko, Key factors influencing wider adoption of blue-green infrastructure in developing cities, Water (Switzerland) (2019) 11, https://doi.org/10.3390/w11061234.
[52] I. Andrés-Doménech, J. Anta, S. Perales-Momparler, J. Rodriguez-Hernandez, Sustainable urban drainage systems in Spain: a diagnosis, Sustain. Times 13 (2021) 1–22, https://doi.org/10.3390/su13052791.
[53] E.C. O'Donnell, J.E. Lamond, C.R. Thorne, Recognising barriers to implementation of Blue-Green Infrastructure: a Newcastle case study, Urban Water J. 14 (2017) 964–971, https://doi.org/10.1080/1573062X.2017.1279190.
[54] C.M. Johns, Understanding barriers to green infrastructure policy and stormwater management in the City of Toronto: a shift from grey to green or policy layering and conversion? J. Environ. Plann. Manag. 62 (2019) 1377–1401, https://doi.org/10.1080/09640568.2018.1496072.
[55] C.M. Raymond, N. Frantzeskaki, N. Kabisch, P. Berry, M. Breil, M.R. Nita, D. Geneletti, C. Calfapietra, A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas, Environ. Sci. Pol. 77 (2017) 15–24, https://doi.org/10.1016/j.envsci.2017.07.008.
[56] TEEB, Ecosystem Services, (n.d, http://www.teebweb.org/resources/ecosystem-services/ (Accessed 6 June 2020) accessed.
[57] J. Uribe-Aguado, S.L. Jiménez-Ariza, M.N. Torres, N.A. Bernal, M.M. Giraldo-González, J.P. Rodríguez, A SUDS planning decision support tool to maximize ecosystem services, Sustain. Times 14 (2022) 1–22, https://doi.org/10.3390/su14084560.
[58] J.R. Vogel, T.L. Moore, R.R. Coffman, S.N. Rodie, S.L. Hutchinson, K.R. McDonough, A.J. McLemore, J.T. McMaine, Critical review of technical questions facing low impact development and green infrastructure: a perspective from the great plains, Water Environ. Res. 87 (2015) 849–862, https://doi.org/10.2175/106143015x14362865226392.
[59] J. Ossa-Moreno, K.M. Smith, A. Mijic, Economic analysis of wider benefits to facilitate SuDS uptake in London, UK, Sustain. Cities Soc. 28 (2017) 411–419, https://doi.org/10.1016/j.scs.2016.10.002.
[60] y DANE Censo Nacional de Población, Vivienda 2018 (2018). https://www.dane.gov.co/index.php/estadisticas-por-tema/demografia-y-poblacion/censo-nacional-de-poblacion-y-vivenda-2018/cuantos-somos.
[61] C. Henríquez, H. Romero, Urban Climates in Latin America, 2019, https://doi.org/10.1007/978-3-319-97013-4_8.
[62] I.K. Parés-Ramos, N.L. Álvarez-Berríos, T.M. Aide, Mapping urbanization dynamics in major cities of Colombia, Ecuador, Perú, and Bolivia using night-time satellite imagery, Land 2 (2013) 37–59, https://doi.org/10.3390/land2010037.
[63] J. Salazar Ferro, Bogotá's recovery process, in: A. Sorensen, J. Okata (Eds.), Megacities Urban Form, Governance, Sustain., 2011, https://doi.org/10.1111/juaf.12120.
[64] G. Wessels, C.F. Pardo, J.P. Bocarejo, Bogotá 21: towards a World-Class, Transit-Oriented Metropolis, 2012.
[65] C. Rojas, Settling with waters. Design investigations for flood adaptation in the Sabana de Bogotá, Labor Eng 12 (2018) 71–89.
[66] IDEAM, Características climatológicas de ciudades principales y municipios turísticos, Bogotá, 2014. http://www.ideam.gov.co/web/tiempo-y-clima/clima.
[67] IDIGER, Documento técnico de soporte, Mapa de amenaza por inundación por desbordamiento en perspectiva de cambio climático zona urbana y de expansión, Bogotá, 2018.
[68] Comisión Ambiental Local, Diagnóstico Ambiental de la Localidad de Bosa, Bogotá, 2012.
[69] IDIGER, Plan de Acción Específico Primera Temporada de Lluvias 2021, 2021.
[70] S.J. Van de Meene, R.R. Brown, M.A. Farrelly, Towards understanding governance for sustainable urban water management, Global Environ. Change 21 (2011) 1117–1127, https://doi.org/10.1016/j.gloenvcha.2011.04.003.
[71] R. Giordano, I. Pluchinotta, A. Pagano, A. Scrieciu, F. Nanu, Enhancing nature-based solutions acceptance through stakeholders' engagement in co-benefits identification and trade-offs analysis, Sci. Total Environ. 713 (2020) 136552, https://doi.org/10.1016/j.scitotenv.2020.136552.
[72] S.A. Forrest, E.M. Trell, J. Woltjer, Emerging citizen contributions, roles and interactions with public authorities in Dutch pluvial flood risk management, Int. J. Water Resour. Dev. (2020) 1–23, https://doi.org/10.1080/07900627.2019.1701999.
[73] S.A. Maskrey, N.J. Mount, C.R. Thorne, I. Dryden, Participatory modelling for stakeholder involvement in the development of flood risk management intervention options, Environ. Model. Software 82 (2016) 275–294, https://doi.org/10.1016/j.envsoft.2016.04.027.
[74] T.T. De Lopez, Stakeholder management for conservation projects: a case study of Ream National Park, Cambodia, Environ. Manag. 28 (2001) 47–60, https://doi.org/10.1007/s002670010206.
[75] G. Jerome, D. Sinnett, S. Burgess, T. Calvert, R. Mortlock, A framework for assessing the quality of green infrastructure in the built environment in the UK, Urban For. Urban Green. 40 (2019) 174–182, https://doi.org/10.1016/j.ufug.2019.04.001.
[76] S. Connop, P. Vandergert, B. Eisenberg, M.J. Collier, C. Nash, J. Clough, D. Newport, Renaturing cities using a regionally-focused biodiversity-led multifunctional benefits approach to urban green infrastructure, Environ. Sci. Pol. 62 (2016) 99–111, https://doi.org/10.1016/j.envsci.2016.01.013.
[77] J. Lamond, G. Everett, Sustainable Blue-Green Infrastructure: a social practice approach to understanding community preferences and stewardship, Landsc. Urban Plann. 191 (2019) 103639, https://doi.org/10.1016/j.landurbplan.2019.103639.
[78] W. Galindo, Dinámica de las construcciones por usos de la localidad de Bosa en los años 2002 y 2012, 2013. https://www.catastrobogota.gov.co/sites/default/files/4.pdf.
[79] N. Mack, C. Woodsong, K. MacQueen, G. Guest, E. Namey, Qualitative Research Methods: A Data Collector's Field Guide, Family Health International, 2005.
[80] M. Torrentira, Online data collection as adaptation in conducting quantitative and qualitative research during the covid-19 pandemic, Eur. J. Educ. Stud. 7 (2020) 78–87, https://doi.org/10.46827/ejes.v7i11.3336.
[81] J.K. Roberts, A.E. Pavlakis, M.P. Richards, It's more complicated than it seems: virtual qualitative research in the COVID-19 era, Int. J. Qual. Methods 20 (2021) 1–13, https://doi.org/10.1177/16094069211002959.
[82] G. Everett, J. Lamond, A.T. Morzillo, A.M. Matsler, F.K.S. Chan, Delivering Green Streets: an exploration of changing perceptions and behaviours over time around bioswales in Portland, Oregon, J. Flood Risk Manag. 11 (2018) S973 https://doi.org/10.1111/jfr3.12225, –S985.
[83] A.N. Carriquiry, D. Sauri, H. March, Community involvement in the implementation of sustainable urban drainage systems (SUDSs): the case of Bon Pastor, Barcelona, Sustain 12 (2020) 1–19, https://doi.org/10.3390/su12020510.
[84] M.C. Aceves, M. Fuamba, Methodology for selecting Best Management Practices integrating multiple stakeholders and criteria. Part 2: case study, Water (Switzerland) 8 (2016) 1–19, https://doi.org/10.3390/w8020056.
[85] V. Braun, V. Clarke, Using thematic analysis in psychology, Qual. Res. Psychol. 3 (2006) 77–101, https://doi.org/10.1191/1478088706qp063oa.
[86] V. Braun, V. Clarke, Successful Qualitative Research: A Practical Guide for Beginners, SAGE Publications, 2013. https://books.google.de/books?id=EV_

Q06CUsXsC.
[87] E. Krkoška Lorencová, L. Slavíková, A. Emmer, E. Vejchodská, K. Rybová, D. Vačkářová, Stakeholder engagement and institutional context features of the ecosystem-based approaches in urban adaptation planning in the Czech Republic, Urban For. Urban Green. 58 (2021) 126955, https://doi.org/10.1016/j.ufug.2020.126955.
[88] R.H. Bark, J. Martin-Ortega, K.A. Waylen, Stakeholders' views on natural flood management: implications for the nature-based solutions paradigm shift? Environ. Sci. Pol. 115 (2021) 91–98, https://doi.org/10.1016/j.envsci.2020.10.018.
[89] H.J. Davies, K.J. Doick, M.D. Hudson, K. Schreckenberg, Challenges for tree officers to enhance the provision of regulating ecosystem services from urban forests, Environ. Res. 156 (2017) 97–107, https://doi.org/10.1016/j.envres.2017.03.020.
[90] A.G. Tuckett, Applying thematic analysis theory to practice: a researcher's experience, Contemp. Nurse a J. Aust. Nurs. Prof. 19 (2005) 75–87, https://doi.org/10.5172/conu.19.1-2.75.
[91] N. Kalpokaite, I. Radivojevic, Demystifying qualitative data analysis for novice qualitative researchers, Qual. Rep. 24 (2019) 44–57, https://doi.org/10.46743/2160-3715/2019.4120.
[92] S. McEvoy, F.H.M. van de Ven, A.G. Santander, J.H. Slinger, The influence of context on the use and added value of Planning Support Systems in workshops: an exploratory case study of climate adaptation planning in Guayaquil, Ecuador, Comput, Environ. Urban Syst. 77 (2019) 101353, https://doi.org/10.1016/j.compenvurbsys.2019.101353.
[93] C.P. Tseng, E.C. Penning-Rowsell, Micro-political and related barriers to stakeholder engagement in flood risk management, Geogr. J. 178 (2012) 253–269, https://doi.org/10.1111/j.1475-4959.2012.00464.x.
[94] K. Louise Barriball, A. While, Collecting data using a semi-structured interview: a discussion paper, J. Adv. Nurs. 19 (1994) 328–335, https://doi.org/10.1111/j.1365-2648.1994.tb01088.x.
[95] Ministry of Housing of Colombia, Reglamento Técnico para el Sector Agua Potable y Saneamiento Básico, – RAS, Colombia, 2021.
[96] S. Sarabi, Q. Han, A.G.L. Romme, B. de Vries, R. Valkenburg, E. den Ouden, Uptake and implementation of nature-based solutions: an analysis of barriers using interpretive structural modeling, J. Environ. Manag. 270 (2020) 110749, https://doi.org/10.1016/j.jenvman.2020.110749.
[97] Ministry of Housing of Colombia, y VIP. VIS, https://www.minvivienda.gov.co/viceministerio-de-vivienda/vis-y-vip#:~:text=Vivienda%20de%20Interés%20Social%20(VIS,mensuales%20vigentes%20(135%20SMLM, 2020. (Accessed 19 January 2022) accessed.
[98] A. McVittie, L. Cole, A. Wreford, A. Sgobbi, B. Yordi, Ecosystem-based solutions for disaster risk reduction: lessons from European applications of ecosystem-based adaptation measures, Int. J. Disaster Risk Reduc. 32 (2018) 42–54, https://doi.org/10.1016/j.ijdrr.2017.12.014.
[99] V. Pappalardo, D. La Rosa, A. Campisano, P. La Greca, The potential of green infrastructure application in urban runoff control for land use planning: a preliminary evaluation from a southern Italy case study, Ecosyst. Serv. (2017), https://doi.org/10.1016/j.ecoser.2017.04.015.
[100] U. Wehn, M. Rusca, J. Evers, V. Lanfranchi, Participation in flood risk management and the potential of citizen observatories: a governance analysis, Environ. Sci. Pol. 48 (2015) 225–236, https://doi.org/10.1016/j.envsci.2014.12.017.
[101] M. Rubinato, A. Nichols, Y. Peng, J. min Zhang, C. Lashford, Y. peng Cai, P. zhi Lin, S. Tait, Urban and river flooding: comparison of flood risk management approaches in the UK and China and an assessment of future knowledge needs, Water Sci. Eng. 12 (2019) 274–283, https://doi.org/10.1016/j.wse.2019.12.004.
[102] M. Buchecker, D.M. Ogasa, E. Maidl, How well do the wider public accept integrated flood risk management? An empirical study in two Swiss Alpine valleys, Environ. Sci. Pol. 55 (2016) 309–317, https://doi.org/10.1016/j.envsci.2015.07.021.
[103] M.P. Mohanty, S. Mudgil, S. Karmakar, Flood management in India: a focussed review on the current status and future challenges, Int. J. Disaster Risk Reduc. 49 (2020) 101660, https://doi.org/10.1016/j.ijdrr.2020.101660.
[104] S. Santoro, I. Pluchinotta, A. Pagano, P. Pengal, B. Cokan, R. Giordano, Assessing stakeholders' risk perception to promote Nature Based Solutions as flood protection strategies: the case of the Glinščica river (Slovenia), Sci. Total Environ. 655 (2019) 188–201, https://doi.org/10.1016/j.scitotenv.2018.11.116.
[105] J. Qiu, Z. Shen, L. Chen, H. Xie, C. Sun, Q. Huang, The stakeholder preference for best management practices in the three gorges reservoir region, Environ. Manag. 54 (2014) 1163–1174, https://doi.org/10.1007/s00267-014-0324-9.
[106] V. Chen, J.R. Bonilla Brenes, F. Chapa, J. Hack, Development and modelling of realistic retrofitted Nature-based Solution scenarios to reduce flood occurrence at the catchment scale, Ambio 50 (2021) 1462–1476, https://doi.org/10.1007/s13280-020-01493-8.
[107] R.H. Bark, M.C. Acreman, Investigating social processes that underpin local flood risk management action, Environ. Sci. Pol. 109 (2020) 95–102, https://doi.org/10.1016/j.envsci.2020.04.009.
[108] S.L. Hamlin, M. Nielsen-Pincus, From gray copycats to green wolves: policy and infrastructure for flood risk management, J. Environ. Plann. Manag. 64 (2021) 1599–1621, https://doi.org/10.1080/09640568.2020.1835619.
[109] H.Q. Nguyen, M. Radhakrishnan, T.K.N. Bui, D.D. Tran, L.P. Ho, V.T. Tong, L.T.P. Huynh, N.X.Q. Chau, T.T.T. Ngo, A. Pathirana, H.L. Ho, Evaluation of retrofitting responses to urban flood risk in Ho Chi Minh City using the Motivation and Ability (MOTA) framework, Sustain. Cities Soc. 47 (2019) 101465, https://doi.org/10.1016/j.scs.2019.101465.
[110] F. Mukhtarov, C. Dieperink, P. Driessen, J. Riley, Collaborative learning for policy innovations: sustainable urban drainage systems in Leicester, England, J. Environ. Pol. Plann. 21 (2019) 288–301, https://doi.org/10.1080/1523908X.2019.1627864.
[111] J. Lamond, G. Everett, K. England, Citizen and community understanding, preferences and behaviours with respect to blue–green infrastructure, Blue–Green Cities (2020) 99–114, https://doi.org/10.1680/bgc.64195.099.
[112] Universidad de los Andes, Capítulo 6: resultados de los indicadores y opciones en Ciudad Verde, in: Syst. Perspect. Low-Carbon Cities Colomb. An Integr. Urban Model. Approach Policy Regul, Anal., 2020. https://electricayelectronica.uniandes.edu.co/sites/default/files/proyectos/InfoFinal_Capitulo_6.pdf.
[113] A.F. Vasconcelos, A.P. Barbassa, M.F.N. dos Santos, M.A. Imani, Barriers to sustainable urban stormwater management in developing countries: the case of Brazil, Land Use Pol. 112 (2022), https://doi.org/10.1016/j.landusepol.2021.105821.
[114] S. Janssen, H. Vreugdenhil, L. Hermans, J. Slinger, On the nature based flood defence dilemma and its Resolution: a game theory based analysis, Sci. Total Environ. 705 (2020) 135359, https://doi.org/10.1016/j.scitotenv.2019.135359.
[115] M. Hu, X. Zhang, Y.L. Siu, Y. Li, K. Tanaka, H. Yang, Y. Xu, Flood mitigation by permeable pavements in Chinese sponge city construction, Water (Switzerland) 10 (2018) 1–12, https://doi.org/10.3390/w10020172.
[116] A. D'Aniello, L. Cimorelli, L. Cozzolino, D. Pianese, The effect of geological heterogeneity and groundwater table depth on the hydraulic performance of stormwater infiltration facilities, Water Resour. Manag. 33 (2019) 1147–1166, https://doi.org/10.1007/s11269-019-02404-7.
[117] J.B. Ellis, C. Viavattene, Sustainable urban drainage system modeling for managing urban surface water flood risk, Clean 42 (2014) 153–159, https://doi.org/10.1002/clen.201300225.
[118] G. Krebs, T. Kokkonen, M. Valtanen, H. Koivusalo, H. Setälä, A high resolution application of a stormwater management model (SWMM) using genetic parameter optimization, Urban Water J. 10 (2013) 394–410, https://doi.org/10.1080/1573062X.2012.739631.
[119] B.C. Ferguson, R.R. Brown, N. Frantzeskaki, F.J. de Haan, A. Deletic, The enabling institutional context for integrated water management: lessons from Melbourne, Water Res. 47 (2013) 7300–7314, https://doi.org/10.1016/j.watres.2013.09.045.
[120] T.C. Wild, J. Henneberry, L. Gill, Comprehending the multiple "values" of green infrastructure - valuing nature-based solutions for urban water management, from multiple perspectives 158 (2017) 179–187.
[121] P. Sukhdev, H. Wittmer, C. Schröter-Schlaack, C. Nesshöver, J. Bishop, P. ten Brink, H. Gundimeda, P. Kumar, B. Simmons, The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB, 2010.
[122] A. Alves, Z. Vojinovic, Z. Kapelan, A. Sanchez, B. Gersonius, Exploring trade-offs among the multiple benefits of green-blue-grey infrastructure for urban flood mitigation, Sci. Total Environ. 703 (2020) 134980, https://doi.org/10.1016/j.scitotenv.2019.134980.
[123] S. Kok, A. Bisaro, M. de Bel, J. Hinkel, L.M. Bouwer, The potential of nature-based flood defences to leverage public investment in coastal adaptation: cases from The Netherlands, Indonesia and Georgia, Ecol. Econ. 179 (2021) 106828, https://doi.org/10.1016/j.ecolecon.2020.106828.
[124] A.H. Roy, S.J. Wenger, T.D. Fletcher, C.J. Walsh, A.R. Ladson, W.D. Shuster, H.W. Thurston, R.R. Brown, Impediments and solutions to sustainable, watershed-scale urban stormwater management: lessons from Australia and the United States, Environ. Manag. 42 (2008) 344–359, https://doi.org/10.1007/

s00267-008-9119-1.

[125] M. Francesch-Huidobro, Collaborative governance and environmental authority for adaptive flood risk: recreating sustainable coastal cities: theme 3: pathways towards urban modes that support regenerative sustainability, J. Clean. Prod. 107 (2015) 568–580, https://doi.org/10.1016/j.jclepro.2015.05.045.

[126] R.K. Yin, Case Study Research: Design and Methods, SAGE Publications, 2009. https://books.google.com.co/books?id=FzawIAdilHkC.