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The Main Challenges for Improving Urban Drainage Systems from the Perspective of Brazilian Professionals

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Abstract: Urban drainage systems play an important role in the complex ecosystem of cities and are often subject to challenges that hinder their functioning. Although identifying these challenges is essential for developing policies and actions to improve drainage systems, there is a lack of studies addressing these challenges. This work has two objectives to contribute to filling this gap: (1) to research the main challenges that make it difficult to improve urban drainage systems; and (2) to prioritize them. We conducted extensive and detailed bibliographic research in which 15 challenges were identified, and a survey with 30 Brazilian professionals with experience in the concerned field. The results showed that 15 challenges identified in the literature were considered important by the survey respondents. It also showed that the most important challenges concern the inadequate functioning of drainage infrastructure, dynamics of city expansion, system maintenance, vulnerability of urban areas, public policies, and investments.

Keywords: urban drainage; rainwater; stormwater; flood; challenge; barrier; public policies; sustainable drainage

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1. Introduction

Ensuring the proper functioning of the urban drainage system has been a challenge in most cities in developing and underdeveloped countries. As a result, frequent reports of flooding tend to worsen with the effects caused by climate change [1].

The urban drainage system influences and is influenced by the city expansion process, which often occurs disorganizedly. Increasing urbanization has led to increased impervious surfaces [1–3], such as roads, parking lots, and roofs, and a reduction in forested areas and other forms of open space that absorb rainwater. The change in the water balance, caused mainly by the growth of impervious surfaces, has caused significant changes in the quality and quantity of rainwater runoff [4,5].

The quality of the drainage system is also hampered by the fact that the implementation of the system is expensive, especially in countries where artisanal construction processes still predominate. This scenario, associated with the scarcity of resources faced by most developing and underdeveloped countries, makes it difficult for public investment to implement, expand, maintain and modernize drainage systems.

More recently, the importance of developing more sustainable and intelligent drainage systems has grown [6], which, as it is a multidisciplinary field of research, demands professionals with different backgrounds to integrate different approaches.

In the researched literature, it is possible to identify the predominance of four focuses of studies on urban drainage systems: (a) studies related to the interaction of the drainage system with sustainability, which mainly addresses the impacts, challenges, and drivers;

(b) studies that address specific aspects of drainage systems, such as the design, maintenance, and management of the system; (c) studies that address urban stormwater flooding; and (d) studies that address the resilience of the urban drainage system.

Regarding the first approach, Neil Armitage [7] researched the main challenges for sustainable drainage in developing countries and identified the inability of local governments to provide adequate local services to the crowds departing for cities. Fenner [8] researched the challenges to adopting green infrastructure in Newcastle, U.K., through semi-structured interviews with professionals, classifying the most relevant challenges as those related to the sociopolitical system. Wihlborg et al. [9] researched barriers and drivers in implementing blue-green measures in a Swedish context to increase the understanding of how they could be implemented more successfully. Based on semi-structured interviews, the authors highlight factors such as climate change, economic factors, urban densification, lack of knowledge, and policies. Li et al. [10] identified barriers and enablers for adopting green infrastructure by investigating Sustainable Urban Drainage Systems and Sponge Cities Programs in the U.K. and China. They found many similarities in the barriers and enablers, despite the political, cultural, and social differences between China and the U.K. This study also found that the most important challenge was financing, both in upfront costs and maintenance. Pappalardo and Rosa [11] discussed different approaches to adopting Sustainable Urban Drainage Systems. They started with identifying a set of "performance-based criteria," which served as a basis for analyzing criticalities, challenges, and general implications for implementing the different types of policies in new and existing urban developments. Marsalek [5] reviewed the current state of the art in urban drainage, emphasizing drainage impacts on the receiving waters, means of impact mitigation, and implementation of management programs. Houng e Fenner [12] evaluated the complexities that can arise in the technical or organizational system in the interaction of the stormwater management system using the sustainable drainage system and green infrastructure. Miguez [13] et al., in their case study in a developing area of the metropolitan region of Rio de Janeiro, Brazil, discuss the need to link the master drainage plan with the master plan, pointing to the importance of urban planning, especially in terms of respect to the control of land use.

Regarding the second approach, Parkinson [14] addressed the challenges for urban planners and engineers in the design of urban drainage and stormwater management systems in developing countries. He concluded that the financing and cost-recovery of urban drainage systems and their operation and maintenance are major challenges. It also underscores the importance of collaboration between government agencies and non-governmental organizations and community consultation. Loggia et al. [15] addressed the philosophy of urban drainage design. The authors emphasize that urban planning must integrate stakeholders and authorities. They also emphasize that it is necessary to develop a new type of urban drainage system through which water, land use, ecology, transport, and the nexus between society and economy are considered together from a multi-stakeholder perspective. Leeuwen [16] researched the water management challenges and showed the importance of involving civil society and private entities from the beginning of the management process to achieve success and collaboration between cities and regions and share best practices. They conclude that innovative urban water approaches are needed that enable integrated solutions, such as water-sensitive design, including rainwater harvesting, recycling, reuse, and pollution prevention. Novaes and Marques [17] discussed the political aspects of urban stormwater drainage and management services. They concluded that cities' fragile conditions on rainfall events reflect the results obtained with existing policies or their absence, which invariably result in inconvenience and material and human losses, whether in developed or developing countries. They would also conclude that policies must be flexible and embrace the concept of dynamic resilience of complex urban systems and the infrastructure that supports them. Carlson [18] in order to identify elements for better stormwater management to help the community, introduces the concept of the provision of the public good' and applies this concept to stormwater management. Brasil [19] explores the opportunities of jointly applying the techniques of nature-based solutions (N.B.S.) and real-time control (R.T.C.) to report challenges and perform an analysis of these techniques and their potential benefits for drainage systems. Ribeiro et al. [20] analyzed the new legal framework (law 14,026/2020) regarding approaches to urban drainage in Brazil and concluded that it did not bring significant changes in stormwater management concerning law 11,445 of 2007. Assumpção et al. [21] performed an exploratory analysis of three Brazilian public policies: national water resources policy (law n° 9433/1997), federal basic sanitation policy (law nº 11,445/2007), and national protection policy and civil defense (law n° 12.608/2012), exploring the hypothesis that the interaction, compliance, social control and inspection of these policies minimize the consequences of extreme events and prevent small disasters. Moreira [22] made a critical assessment of the urban crisis in Brazilian cities and concluded that establishing general norms on urban policies to be applied nationwide is a complex task and presents the master plan as a manager of conflict situations between different interests that seek to appropriate the benefits produced in the city.

Regarding the third approach, Torgersen [23], in his comparative study of the largest Scandinavian cities, noted three challenges related to urban flooding in cities: climate change, rapid urbanization, and poorly designed sewers. Limthongsakul et al. [3] explored the causes of localized flooding after average rainfall, its impacts on local communities, and how autonomous adaptation affects the community's stormwater drainage systems. Kong et al. [24] analyze the main characteristics and process of urban stormwater governance in China, explain the disasters caused by this mechanism, and discuss the causes of urban stormwater flooding in China. Finally, Junior et al. [25], focusing on Recife -Brazil, made a diagnosis highlighting the main problems and peculiarities of local drainage and initiatives for mitigating impacts and adapting urban drainage infrastructure.

Regarding the fourth approach, Yazdanfar and Sharma [26] researched the challenges of urban drainage systems and the limitations and potential of adaptation alternatives. They concluded that urbanization and climate change are the two major issues impacting the performance of conventional drainage systems. They also concluded that implementing and managing integrated approaches to urban water management have significant impediments due to knowledge gaps and the involvement of stakeholders with conflicting interests. Galarza-Molina [27] conducted an extensive literature review to identify how urban drainage system resilience has been incorporated into public policies worldwide. They focused on identifying the characteristics, instruments, and methodologies involved in the strategies used by countries that have been successful in urban water management and how they can be used to promote resilience in an urban water management context in cities in developing countries. Finally, Wilby [28] analyzes the steps actors at international, regional, and community levels take to adapt to the challenge of flooding from the river.

Underdeveloped and developing countries have similar characteristics influencing the quality of their cities' drainage systems. In Brazil, for example, for a long time, urban drainage had little relevance in discussions and actions related to the infrastructure of cities [20]. In addition, the accelerated process of urbanization and ineffective population policies resulted in structural problems for most Brazilian cities [25], which influence urban drainage, such as, for example, the disorderly occupation of unsuitable areas for human habitation and rapid growth population of regions of the city. In the first case, there was an increase in areas without adequate infrastructure for basic sanitation, urban drainage, and proper waste disposal [20], while in the second, the need for interventions in the drainage network to readjust its hydraulic capacity [13].

Among essential sanitation services, urban drainage is the one that has received the least attention from Brazilian policymakers and public managers [21]. In addition, the need for budgetary resources and new financing mechanisms for drainage infrastructure is continuously increasing due to regulatory requirements, degradation of water quality, flood risks, climate change, and the aging infrastructure itself [17].

The reality contextualized above, characterized mainly by the disorderly expansion of cities, growth of slums, scarcity of budgetary resources, inadequate population behavior, and obsolete drainage systems, is also experienced to a greater or lesser extent by a significant portion of underdeveloped and developing countries and create challenges to the improvement of drainage systems.

Although understanding the challenges is fundamental for improving urban drainage systems, in the researched literature, we did not find works that addressed the main challenges in an integrated way. Instead, we identified studies that focus on specific aspects, such as those presented in the four focuses of studies on urban drainage systems. Thus, in summary, there are two problems that this work helps to solve. The first problem is the lack of works in the literature that contain an integrated set of challenges for improving urban drainage systems, which can serve as a basis for the actions of managers and professionals who work in urban drainage. The second problem is that no works prioritize challenges according to their potential to impact the improvement of urban drainage systems, so it is possible to identify the most relevant ones.

This work has two objectives to contribute to filling this gap: (1) to research the main challenges that make it difficult to improve urban drainage systems; and (2) to prioritize these challenges from the perspective of Brazilian professionals with experience in the concerned field.

The results of this work allow for significant contributions, mainly related to designers, decision-makers, and society, important actors involved with the context of drainage systems. By exploring the concepts related to the challenges and their degree of relevance concerning designers, this work contributes to the incorporation of new practices into the traditional way of designing systems, especially those related to improving the sustainability and effectiveness of the system. It is important to emphasize that the designers' creativity strongly influences the quality of the drainage system project by using methods, techniques, and procedures that consider local and regional peculiarities, especially aspects related to cost, society, and the environment.

As far as decision-makers are concerned, this work contributes to the decision-making process on which system characteristics and variables should be prioritized. Considering the scarcity of public resources experienced by a significant portion of developing and underdeveloped countries, this work helps municipal managers direct their efforts toward formulating and financing public policies that enhance solutions to problems that make it challenging to improve drainage systems, including structural issues caused by the lack or inefficiency of services.

Concerning the population, this work contributes to improving the quality of life since more effective drainage systems generate several benefits, such as reducing the incidence of waterborne diseases [14] and reducing human losses and property damage [4].

This article is structured as follows: Section 2 presents the procedures used to carry out the bibliographic research, the identification of the challenges, the survey of expert opinions, and data analysis. Section 3 presents and discusses the research results. Finally, conclusions are provided in Section 4.

2. Materials and Methods

2.1. Approach

This study has two main objectives: (1) to research the main challenges to improving urban drainage systems; and (2) to prioritize these barriers from the point of view of professionals who work in the concerned field. To achieve these objectives, we use an exploratory approach frequently used in research aimed at identifying variables related to a given phenomenon and the degree of importance of these variables. It is mainly based on obtaining information from a systematic literature review and survey with professionals in the concerned field. We adopted this method because our objective was not to draw statistical conclusions but mainly to look for patterns and provide insights into an understudied topic.

Our approach consists of three steps:

(a) Identification of challenges for urban drainage systems improvement: We researched works that adhered to the theme to identify challenges for improving urban drainage systems. In this sense, we carried out extensive and detailed bibliographic research on the Web of Science, Scopus, Scielo, and the websites of the main scientific journals;

(b) Challenges prioritization: We used the vision of Brazilian professionals with experience in the concerned field to prioritize the challenges identified in the literature due to their potential impact on improving urban drainage systems.

(c) Data Analysis: To prioritize the challenges, we transformed the psychometric data obtained from the professionals' judgment into ordinal data and used the concept of relative median described in Section 2.3. To assess data quality, we used Cronbach's alpha.

The three steps will be detailed below.

2.2. Identification of Challenges for Urban Drainage Systems Improvement

To identify works that could contribute to the theme of this work, we carried out a wide and detailed bibliographical research on Web of Science, Scopus, Scielo, and the websites of the main scientific journals. The keywords to carry out bibliographic research were "urban drainage," "barriers," and "challenges". We adopted the recommendations of Munhoz et al. [29] and those contained in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (P.R.I.S.M.A.) [30]. We adopted the P.R.I.S.M.A. phases to synthesize the bibliographic search results, highlighting the number of articles identified, the number of articles included, the number of articles excluded, and the reason for the removal of articles [31].

Initially, we quickly read titles and abstracts to select the works with some evidence or information on the subject of this work. Of the 1944 articles initially identified from the keywords, 118 articles were pre-selected. Papers that did not have a clear summary to identify their relevance and did not contain content relevant to the researched topic were not peer-reviewed, and those that did not provide full text were excluded. Then, we performed a selective reading of the 118 articles to confirm whether the initial perception of the relevance of the content to the topic was correct; 71 articles were excluded. Works that were not original, that were insufficiently described, and whose results were not supported by the methodology were excluded. Finally, the 41 articles were read in detail and considered adequate to support the work. Figure 1 summarizes the bibliographic research using the P.R.I.S.M.A. flowchart.

To identify the challenges, we searched for works with the following characteristics: works whose objective is to identify challenges or barriers to improving urban drainage; works whose objective is not to identify challenges or barriers to improving urban drainage but which, at some point in the context or analysis, cite some challenge or barrier; works in which the authors do not use the terms challenge or barrier to refer to a specific situation, but their approach characterizes that situation as a challenge. Table 1 presents the selected works grouped according to these characteristics.

Table 1. Characteristics of the selected works.

Characteristics	Authors
Work whose objective is to identify challenges or barriers to improving urban drainage.	[5,7,9,10,13,14,16,19,25,26,32–34]
Papers whose objective is not to identify challenges or barriers to improving urban drainage but which, at some point in the context or analysis, cite some challenge or barrier.	[1–4,6,8,11,12,15,17,18,20,22–24,27,28,31,35–60]
Works in which the authors do not use the terms challenge or barrier to refer to a specific situation, but their approach characterizes that situation as a challenge.	[21,61–66]
Works only used for the contextualization of the theme.	[29,30]

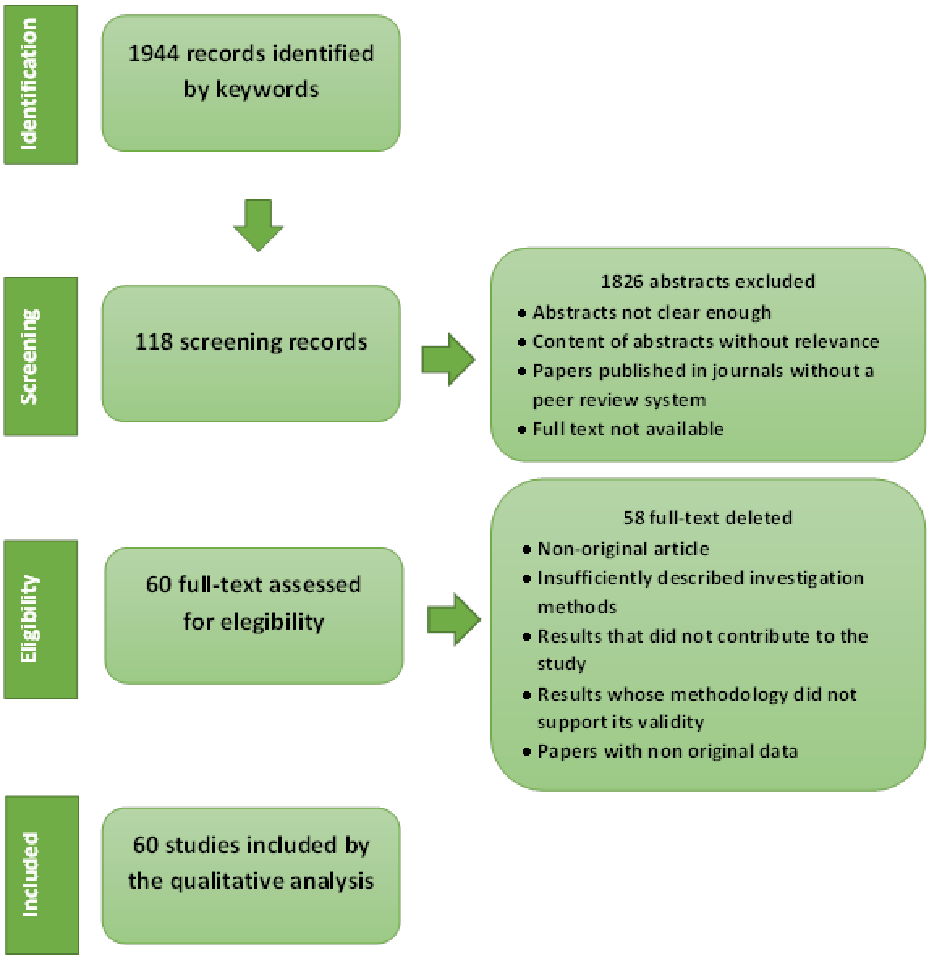

Figure 1. Bibliographic research from the P.R.I.S.M.A. flowchart.

2.3. Challenges Prioritization

We used an online platform (Google Forms) to structure a questionnaire containing three sections:

(a) Conceptualization of the challenges: The 15 challenges identified in the literature review were conceptualized to standardize respondents' understanding of the meaning of each challenge. The challenges and respective conceptualizations can be seen in Table 5 from Section 3.1;

(b) Questions regarding demographic data: We asked about the field of work, length of professional experience, and highest academic specialization. Tables 2–4 synthesize the sample profile.

(c) Questions addressing the importance of challenges identified in the research literature: The question presented to the respondents was: "Express your opinion on the degree to which the factors below represent a challenge for the improvement of urban drainage systems." Then, through Google forms, the challenges in Table 5 were presented simultaneously to facilitate the comparison between them and randomly to avoid responses being influenced by the order in which they appeared. For each challenge, respondents expressed their professional opinions using a five-point Likert scale, ranging from very little challenging to extremely challenging. The pre-test was carried out to collect opinions on the clarity and relevance of the questions to identify possible inconsistencies or doubts. Data collection was carried out from 19 March, 2022 to 28 April, 2022 and resulted in 30 responses.

Table 2. Academic qualification.

Academic Qualification	Number of Respondents
Doctoral degree	8
Master degree	13
Postgraduate degree	5
Bachelor degree	4

Table 3. Length of professional experience.

Professional Experience	Number of Respondents
Up to 5 years	7
From 5 to 10 years	6
More than 10 years	17

Table 4. Work field.

Work Field	Number of Respondents
Architecture and urbanism	5
Biological Sciences	6
Engineering	9

To ensure that the participants were able to participate in the research, we used purposive sampling through which we selected professionals who are part of the authors' relationship network and identified by at least one of the authors as being able to meet the following inclusion criteria: (a) to hold at least a bachelor's degree; (b) to have experience in the concerned field. Tables 2–4 synthesize the sample profile.

2.4. Data Analysis

Although the authors consider the adopted method to be mainly qualitative, it also has quantitative characteristics when transforming psychometric data obtained from people's judgments into numbers and evaluating them for prioritization. It is important to emphasize that the numerical evaluation considered that the data are ordinal.

As a product of the survey, Google Forms provides a spreadsheet in which the first column contains the name of the respondents, the first line contains the survey questions, and in the cells, the respondents' evaluation regarding each question. For each cell, the psychometric scale is usually converted into an ordinal number so that quantitative analyses can be carried out. Thus, the scale is translated into numbers that typically take the range of an ordinal scale from 1 to 5. The fact that the data are ordinal makes measures of position, such as the median, more suitable for analysis.

To assess data quality, we used Cronbach's alpha, whose value of 0.80 confirmed the reliability of the data. To prioritize the challenges, we used the concept of relative median [34], which made it possible to rank the challenges in each semantic classification of the Likert scale using the formula below. The concept of relative median considers the distance from the median to the closest class.

$$Rm = \left\{ \begin{array}{cc} 1 + \frac{Pr}{j_1} & for\ m = 1 \\ m + \frac{Pr - \left(\Sigma_{i=1}^{m-1} j_{i+1}\right)}{j_i} & for\ \mathbf{2} \leq m < N\ e\ m = \ integer \\ m + \mathbf{0.5} & for\ \mathbf{1} \leq m < N\ and\ m = \ fractional\ number \\ N & for\ m = N \end{array} \right\}$$

where R_m is the relative median, m is the median, P_r is the position of the median, N is the number of respondents, and Ji is the number of respondents who received the semantic classification of "i".

As a result, the evaluated items were ordered according to their potential impact on improving urban drainage systems. It is important to emphasize that the ordinal scale is not transformed into a decimal scale, but a decimal scale is used to show the importance of each item concerning the others. Figure 1 presents the results of this classification. We consider the challenges with the highest value to be more important.

3. Results

3.1. Selected Challenges

A total of 15 challenges were selected according to criteria established in the Materials and Methods (Table 5).

Table 5. Selected challenges.

Challenges	Concepts Presented in the Questionnaire	Referências
Drainage infrastructure with low sustainability	Infrastructures are designed mainly to control the amount of water without adequately considering the sustainability concepts.	[1,14–16,18,26,32,42,43,45,49,52,54–56]
Complexity	The design, operation, and maintenance of urban infrastructure demand technical expertise from several areas of knowledge, which must be adequately managed and made compatible.	[1,4,12,14,18,19,24,26,30,39,43,44,46,48,52,53]
Vulnerability of urban areas	Set of characteristics of urban space that potentiate floods.	[5,12,18,24,44,49,56]
Climate change	Effects of climate change on the spatial and temporal distribution of rainfall events.	[3,18,24,26,28,31,36,38,41,43,49,56]
Investment	Investment of financial resources in works of implantation or expansion of the drainage system and its operation and maintenance improvements.	[3,4,7,10,14,15,18,19,24,28,32,54]
Dynamics of city expansion	Dynamics of changes in the structure and form of cities are mainly due to population growth, land use, and occupation.	[1,2,4,5,7,9,10,14,19,24,26,28,31,33,38,41–43,45,48,49,51,52,56,64]
Inadequate understanding of the system	Limited knowledge of those involved in the urban water management process, mainly due to insufficient information and qualified professionals.	[3,7,8,18,24,26,31,41,43,45,49,52,54,63,65]
Uncertainty	Uncertainties that affect the efficiency and effectiveness of drainage systems, such as those arising from sizing variables and methodologies and from system operating conditions.	[15,18,38]
Monitoring	Systematic collection and analysis of data on the operating conditions of drainage systems.	[11,19,26,32]
Cooperation between interested parties	Cooperation between segments of society and public and private bodies aims at the proper functioning of the drainage system and ensuring that interventions in the system meet their interests.	[1,3,4,14,15,24,26,28,31,40,42,52,53,55]

Table 5. *Cont.*

Challenges	Concepts Presented in the Questionnaire	Referências
Regulatory instruments	Decrees, standards, master plans, and other legal instruments that regulate the implementation, improvement, expansion, and maintenance of drainage systems.	[1,4,7,28,52,55]
Inadequate functioning of drainage infrastructure	The inability of drainage infrastructure to fully meet drainage demands is mainly caused by undersized, deterioration or obsolescence.	[3,4,7,14,18,43]
Maintenance	Actions aimed at maintaining the performance conditions of the drainage system.	[3,14,19,27,57,59,66]
Public policy	Government actions and programs aimed at fully developing the functions of drainage systems.	[4,7,8,14,17,18,21,22,26–28,42,45,54,55,58]
Resilience	The ability of drainage infrastructure to resist, absorb or recover from incoming impacts.	[15,27,49,59]

The barrier drainage infrastructure with low sustainability refers to infrastructures that are designed without adequately considering sustainability concepts. Usually, these infrastructures have been designed only to control the amount of water to avoid flooding. More sustainable practices usually incorporate solutions that allow for higher water retention and infiltration into the soil, such as green roofs, a rainwater collection system in homes, and permeable pavements [43]. Rainwater infiltration contributes to the maintenance of base flows in rivers, and the collection of rainwater, in addition to reducing peak runoff flows, also collaborates with the water supply [14]. Infrastructures with low sustainability are not prepared to face new challenges, such as those imposed by climate change, which increases the occurrence of urban floods [56].

The complexity barrier is related to the fact that the design, operation, and maintenance of urban infrastructure demand technical expertise from several areas of knowledge, which must be properly managed and made compatible, and that the drainage system integrates the complex urban ecosystem. According to Chocat et al. [4], different problem areas, processes, and methods are encompassed by urban drainage, creating a complex environment with an expressive number of specific problems that lead to a great diversity of procedures used. According to Ferguson [39], the complexity of the urban ecosystem is a major challenge for a paradigm shift from traditional drainage perspectives.

The vulnerability of urban areas barrier concerns the set of characteristics of the urban space that potentiate floods. They can be natural, such as geological, hydrological, and geomorphological characteristics or resulting from human actions. The isolated or combined effect of these characteristics can significantly reduce groundwater storage and drainage capacity [24].

The climate change barrier concerns the effects of climate change on the drainage system, mainly those related to the spatial and temporal distribution of rainfall events. Climate change is one of humanity's most critical challenges [43]. Climate change has been widely recognized as a global problem due to its predicted impacts on urban water systems in terms of changes in drainage patterns and urban flooding. Zhou [41] reports that the impact on the drainage system due to climate change can reach an intensity of 20–80%, depending on the region [3]. Furthermore, the impacts of climate change are still not adequately understood, which, according to Yazdanfar [26], is a strong barrier to integrated and effective urban drainage.

The investment barrier concerns the insufficiency of resources demanded by the works of implantation or expansion of drainage systems [24,37,49]. Due to the lack of investment or investment models, civil servants and project leaders choose the most popular way out: tube-based solutions [37].

The dynamics of the cities' expansion are related to changes in the structure and form of cities based mainly on population growth, land use, and occupation [9]. Urbanization alters the original connectivity of many surface water bodies, such as rivers, lakes, and reservoirs, as well as the transformation path of surface water and groundwater. Most of the natural drainage channels of rivers and lakes have been replaced by urban drainage networks, and natural water cycles have become artificial cycles composed of many hydraulic structures, which leads to a considerable change in the trajectory of urban water cycles. Another aspect affected by the expansion of cities is the design pattern of the drainage system, which in many cases, does not meet the drainage needs of the city [52].

The inadequate understanding barrier refers to the limited knowledge of stakeholders in the urban water management process. Insufficient information, such as those from variables and sizing methodologies, hydrological and hydraulic models, system operating conditions, and drainage system capacity, are significant barriers to rainwater management [18] and impair understanding of the system. Another important point is that the combined impact of many important parameters is difficult to estimate, resulting in increased uncertainty and errors [54]. The limited knowledge of the stakeholders potentiates inertia for system improvement.

Monitoring refers to the systematic collection and analysis of real-time data related to the operating conditions of drainage systems. The monitoring challenge is intrinsically associated with the uncertainty affecting drainage system efficiency and effectiveness [18]. Inadequacies or insufficient monitoring causes numerous difficulties in understanding the drainage system's performance, making it impossible to improve urban water management [10]. According to Cotterill [32], when monitoring and evaluation of the system are performed, it is usually descriptive, such as an annual site visit to take pictures and essential routine maintenance. Inadequate monitoring undermines policymaking. In this sense, he emphasizes that the practical implementation of policies depends on data, such as those resulting from the control of the flow volume Pappalardo [11].

Cooperation between stakeholders concerns the inclusion of community and public and private bodies that may affect or be affected by the results of urban water management services, aiming at the better functioning of these services and ensuring that interventions in the system meet their interests [29]. Lack of efficient communication between stakeholders makes work disconnected and restricts drainage efficiency [34]. According to Calcerrada [65], the consensual solutions obtained from the involvement of the interested parties are fundamental to achieving a boost to the sustainable management of rainwater.

Regulatory instruments are decrees, rules, master plans, and other legal instruments that regulate the implementation, improvement, expansion, and maintenance of drainage systems and the roles and responsibilities of institutions. Traditional forms of stormwater management lead to jurisdictional and institutional fragmentation in many cases, which in turn causes institutional overlap and a lack of clear roles between institutions [55].

Inadequate functioning of drainage infrastructure is the inability of drainage infrastructure to fully meet drainage demands, mainly caused by undersized, deterioration, or obsolescence. As the rainwater infrastructure ages, several problems arise [43], which, associated with the inadequacy of the operation of drainage systems, make it difficult for them to function correctly [4]. In addition, drainage systems are being subjected to new challenges, such as those arising from climate change. According to Carlson [18], climate change requires a paradigm shift in stormwater management that leads to the additional capacity to deal with the increase in excess water since a significant portion of drainage systems are undersized and stressed by existing conditions.

The maintenance barrier refers to the insufficiency of actions to maintain the drainage system's performance conditions. System maintenance cannot be neglected, considering the adverse effects that can be caused by system failures [19]. Inadequate maintenance of drainage systems constitutes a potential for flooding events [3].

Public policies refer to governmental actions and programs to fully develop the drainage systems' functions. The participation of public authorities and civil society is crucial for a sustainable transition [42], which is not always the case. In the context of urban water management, policies related to rainwater have been relegated to the background since the main focus has been on water supply and wastewater [17].

Resilience refers to the ability of the drainage infrastructure to adapt to the impacts arising from the change in land cover and recover its functionality. However, the intense urbanization process and the rapid growth of cities cause the drainage patterns to be altered, leading to an increase in the risk of flooding. The resilience of the drainage system is intrinsically related to climate change impacts. According to Gupta [59], increasing the system's resilience with sustainable solutions that collaborate to face climate change is necessary.

3.2. Survey Results

Figure 2 shows the challenges ranked by the relative median.

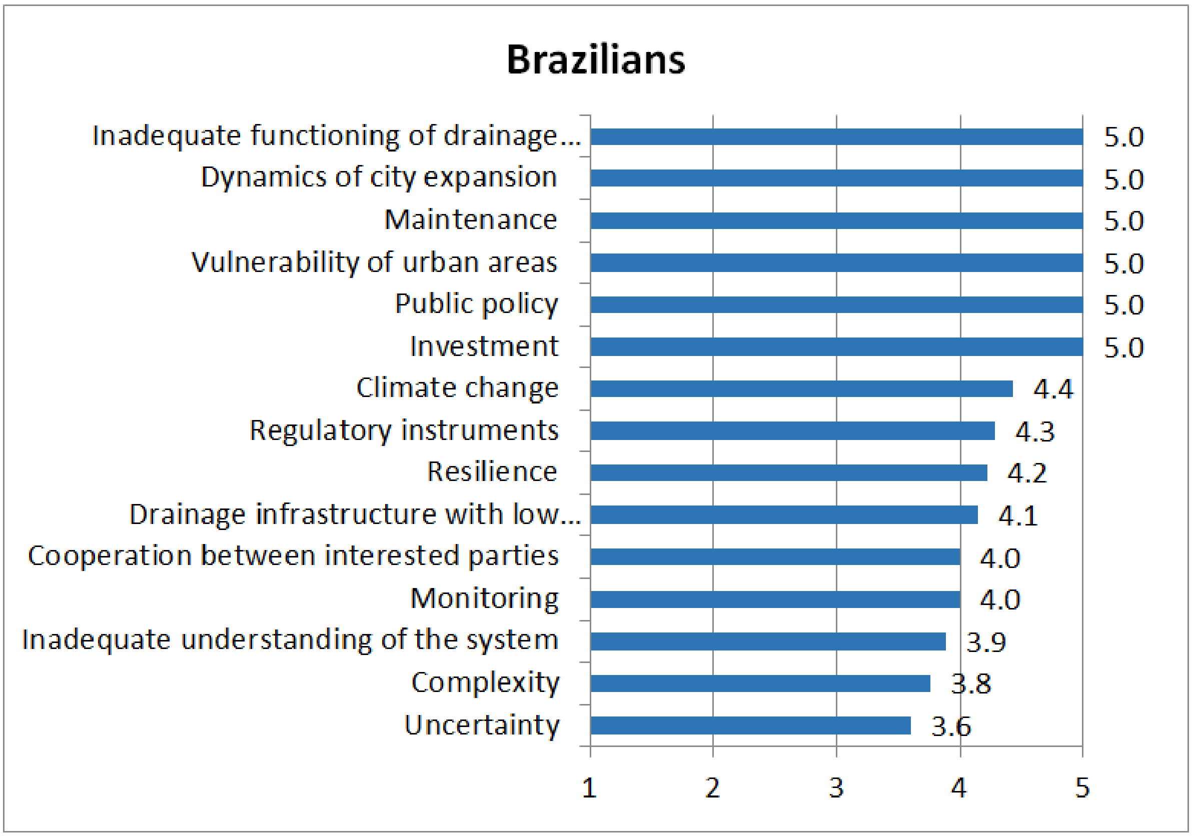

Figure 2. Challenges ranked by relative median.

The respondents considered six challenges as the most important: Inadequate functioning of drainage infrastructure, dynamics of city expansion, Maintenance, Vulnerability of urban areas, Public policy, and Investment.

Regarding the Inadequate functioning of drainage infrastructure, the traditional approach to urban drainage systems often regards stormwater as a waste [1], focusing on collecting stormwater in piped networks and transporting it out of the city as quickly as possible [18,43]. In several situations, more robust modeling is compromised due to the lack of more accurate data. For example, detailed maps of river flood risk in urban areas are widely available in countries, such as the U.S.A. and Europe, while in other regions, is much rarer. Wilby [28] point out that nations such as China, India, Nepal, Bhutan, and Pakistan have bilateral agreements with other countries to exchange meteorological and hydrological data for flood control. Andrés-Domenech et al. [1] highlight the importance of coherent methodologies so that cities' water systems can evolve to better conditions in the future.

As drainage is part of the urban infrastructure, it must be studied and planned in an integrated manner with the other systems that make up the infrastructure to increase the efficiency and effectiveness of the systems and reduce environmental impacts. Perales-Monparler [42] highlights the need to update and improve existing conceptual models to address the complexity of the reality of urban areas.

The dynamics of city expansion have been characterized by intense population growth experienced by a significant portion of cities in developing and underdeveloped countries, which influences the balance of the hydrological cycle.

The balance of the hydrological cycle occurs as a function of infiltration, flow, and percolation processes into the groundwater in lands not influenced by human action. However, the urbanization process produces changes in the ground cover that increase waterproofing and, consequently, the flow of water on the roads.

The fact that in a significant portion of developing and underdeveloped countries, urban infrastructure has not been able to keep up with the dynamics of the expansion of cities, especially in informal urban areas, also contributes to the perception of the inadequacy of the drainage system by the population.

Regarding maintenance, drainage systems are often blocked by rubbish, making the region more prone to flooding during major storms. The operational problems caused by poor solid waste management are exacerbated by the lack of adequate arrangements for clearing drains and pipes, mainly due to the lack of adequate resources, workforce, and equipment [14]. In the absence of adequate services, the drainage system quickly becomes the receptacle for waste of all kinds [7]. In addition, heavy rains, increasingly frequent, can cause landslides on slopes that silt up channels and pipes [46]. When drainage systems fail or are undersized for a given storm, flooding can result in extensive property damage and health problems [14,43]. Furthermore, as highlighted by Cotterill [32], monitoring and evaluation, when they are done, are typically descriptive, ranging from an annual site visit to take pictures to fairly essential routine maintenance.

Concerning technical issues, according to Parkinson [14], the design and construction of urban drainage systems are relatively simple and do not represent significant challenges for managers. However, the same does not apply to subsequent operation and maintenance, as in a significant portion of cities, managers are ineffective in dealing with the scale of the problem.

Concerning vulnerability, drainage systems are strongly influenced by the geological, hydrological, and geomorphological characteristics of the area to be drained, deficiencies in the management of the urban drainage system, and human activities, especially related to the use and land occupation.

In developing and underdeveloped countries, soil sealing caused by the built environment is exacerbated by the lack of regulations that lead to more sustainable land use, such as, for example, the determination of the maximum percentage of built-up area on lots and sidewalks that allow water to seep into the ground. In addition, land use often does not consider the natural flow of water, especially in slum and tenement areas.

The population's inappropriate behavior is the result of its relationship with the drainage system. According to Leme [61], the population's behavior is influenced by several factors, such as social, economic, cultural, and educational factors, that influence how the population interacts with the drainage system and the understanding of the benefits and losses of this interaction.

As noted by Tucci et al. [35], despite institutional advances, it is observed that state administrations, in general, are still not technically and financially prepared to plan and control the impacts of different anthropic actions in hydrographic basins. As a result, water resources continue being treated in a sectored manner (electricity, urban supply, sewage collection and treatment, irrigation, navigation, and other uses).

Addressing vulnerabilities also implies actions aimed at accelerating resilience mechanisms, mainly through public policymakers Georgeson et al. [44].

In Brazil and a significant portion of developing and underdeveloped countries, public policies are strongly influenced by managers' perception of the relationship between the cost of infrastructure works and the visibility of results. Infrastructure works are expensive, usually carried out on public roads, which negatively impacts the daily lives of road users, the population, and local commerce [58], and are of low visibility over time, when compared to those related to other services of the city, such as urban mobility. In this context, in a scenario of scarce resources, investments are generally prioritized for emergency network maintenance actions and specific solutions in areas most affected by floods.

Floods mainly result from the lack of public policies [21]. These are essential to reduce the challenges posed by weaknesses in drainage management. In Brazil, among the weaknesses identified by Tucci [62], the following stand out: (a) at the federal level, the role played is mainly to support municipalities in the form of financing; (b) at the municipal level, there is usually no service provider, leaving the management of the system under the responsibility of professionals from the construction departments; (c) in the professional scope, the lack of professionals who master the most current concepts of urban drainage, is reflected in the unprepared management of the municipality for the development of projects and demands in the sector.

Public policies guide regulatory instruments formed mainly by legislation, technical standards, and recommendations from bodies responsible for approving and monitoring the drainage project. Although the legislation regulating sanitation and land use is considered advanced in Brazil, it still lacks inspection mechanisms that make it responsible for non-compliance. For example, according to Moreira [22], in several municipalities, the master plans, an essential instrument of urban development and expansion policy, are still prepared without reflecting the reality of the city, without respecting its geographical, demographic, and socioeconomic characteristics, and with essentially political and normative character, often intended only to comply with legal requirements of its implementation.

Concerning investments, upgrading stormwater infrastructure in urban environments is expensive, and it is not easy to find funding to maintain this type of infrastructure [18]. In the current context of higher demand for quality of life and environmental preservation associated with the environment of increasing complexity to which rainwater drainage systems are being submitted, the scarcity of financial resources to pay for improvements in the system is being increasingly perceived by society. This context can influence decision-makers to reflect on the financing modalities adopted today and on possible alternatives to ensure adequate financial contributions.

In Brazil, as in a significant portion of developing countries, the resources required for implementing, expanding, and maintaining the urban drainage system are mainly financed by the municipal budget. In the Brazilian case, they are funded by part of the revenue from the Urban Property and Territorial Tax, which has not been sufficient for developing the sector. However, the collection of fees for stormwater drainage or any other direct collection associated with the service provision, although provided in Brazilian legislation, is not a generally adopted practice. Contributing to this scenario are the difficulties imposed by the lack of credibility of the Brazilian public sector, which often distorts the use of fees and taxes destined for a specific purpose, and the fact that this type of measure is very unpopular [62].

According to Carlson [18], municipalities, in addition to not usually investing adequately in drainage systems, face management difficulties, mainly because of funding limitations, lack of coordination, and limited responsibilities, and drainage is not perceived as an essential municipal service.

4. Discussion

The findings show that all challenges were considered important by the respondents (the relative medians were higher than 3.0), corroborating the view of researchers who published on the topic. They also showed that of the 15 challenges identified in the literature, 6 were considered the most important by the respondents who participated in the survey: inadequate functioning of drainage infrastructure, dynamics of city expansion, maintenance, vulnerability of urban areas, public policy, and investment.

The six challenges evaluated as most important are more frequent in underdeveloped and developing countries. However, they may also be present in cities in developed countries to a greater or lesser extent. Contrary to what happens in most cities in developed countries, which have a more consolidated infrastructure, a significant portion of cities in underdeveloped and developing countries still lack drainage systems that adequately fulfill their function. Another important feature is that these six challenges do not occur in isolation, but one enhances the other.

Regarding the challenge of inadequate functioning of drainage infrastructure, it was also identified by authors such as LimthongSakul et al. (2017) and Chocat et al. (2001). LimthongSakul et al. (2017) concluded that inefficient drainage systems are challenging for cities in middle and lower-income countries with rapid economic growth and urbanization. The findings of these authors also corroborate the interrelationship between the challenges by correlating the system's inefficiency with policies and investments. They concluded that inefficient drainage infrastructure systems result from inappropriate policies and lack of funding. Chocat et al. (2001) associate this challenge with the problems of urban water systems operations and the need for expensive rehabilitation.

Some factors contribute to the Inadequate functioning of drainage infrastructure, among which the aging of systems and the emergence of new demands stand out. In many countries, such as Brazil, a significant portion of urban drainage systems was built several decades ago and were not adequately maintained. In addition, these systems were designed for a single objective, to control the amount of water [52], which makes them obsolete in the face of new demands arising from the dynamics of population growth and climate change.

The perception of the inadequacy of the drainage system occurs mainly in regions where flooding is frequent without action being taken by the government. According to Santos et al. [58], the installation and maintenance works of infrastructure systems carried out on the roads occurring at different times, sanitary sewage pipes of homes connected to the rainwater, and vice versa also contribute to this perception. In addition, as highlighted by Carlson et al. [18], under the streets of most cities, several networks coexist in an unplanned way, limiting the space for new infrastructure and increasing pipe diameters, making the work more difficult and time-consuming.

The challenge of the dynamics of city expansion is one of the most cited in the researched literature. Authors such as Andrés-Doménech et al. [1] and Brasil [19] correlate uncontrolled urban growth and the consequent impermeabilization of the soil to the increase in the volume of rainwater runoff, flow peaks, and pollutant loads and concentrations. Huong et al. [31] correlate this challenge with increased flood risk and the vulnerability of cities, due to local changes in hydrological and hydrometeorological conditions. Li et al. [10] also addresses this challenge as a factor in increasing flood risk. They state that the geographical distribution of flood risk is heavily concentrated in the countries with the highest populations.

Authors such as Armitage [7] and Parkinson [14] approach the dynamic of city expansion from the point of view of the growth of areas with poor drainage inhabited by the poorest population. The dynamics of city expansion of a significant portion of cities in developing and underdeveloped countries have been characterized by intense population growth that has caused the disorderly growth of cities. As a consequence, land use formalized through government plans and actions coexists with informal urban conditions, such as slums and peripheries [33]. These conditions are produced by a poor, marginalized and dispossessed civil, social, political, and economic system [51], which does not take into account the urban norms that guide the planning and expansion of drainage systems. Fitchett [45] highlights some reasons that make municipalities reluctant to install a drainage system in informal settlements, such as perceptions of the legitimacy of land occupation by residents, the transitoriness of the settlement's layout, and issues related to the commitment to the safety of residents and environmental degradation.

Regarding the challenge of maintenance, Galarza-Molina [27] and Guptha et al. [59] and Sari et al. [57] also recognize its importance. Sari et al. (2020) and Guptha et al. [59] consider maintenance crucial for the drainage system to be in good physical condition and function correctly. Guptha et al. [59] consider inadequate maintenance as one of the main causes of failures in the drainage system. Galarza-Molina [27] approach to designing urban drainage systems. According to Zuidema and Geiger (1987), the main financial constraints for the reliability and financing of system maintenance operations are one of the main concerns of the cities' master plan. Parkinson correlated this challenge with the ineffectiveness of managers in dealing with the scale of the problem.

Regarding the challenge of public policy, it was also identified by authors such as Li et al. [54], Novaes [17], and Yazdanfar and Sharma [26]. Li et al. (2020) concluded that policy failures are a major challenge to scaling up Sustainable Urban Drainage Systems. Novaes [17] addresses this challenge regarding the need for a paradigm shift, considering a context in which there is a perception that urban rainwater policies are non-existent or incomplete. Yazdanfar and Sharma [26] concluded that there is a need for more holistic policies that enable adaptation strategies for urban drainage system planning and design based on local opportunities and constraints. For Chocat [4], misaligned policies may constrain adaptive flooding capacity.

Regarding the challenge of investment, it was also identified by authors such as Chocat et al. [4], Li et al. [10], and Armitage [7]. Chocat et al. [4] recommend using the adaptive water management approach to face the challenge posed by traditional systems' extremely high investment costs. For Li et al. [10], financial investment restriction is a challenge that limits the functions and potential of drainage infrastructure. The challenge of the need for large investments is emphasized by Armitage [7] concerning temporary settlements, such as the slums found in most cities.

Regarding the scope of the results and limitations, two issues must be considered:

(a) Regarding the 15 challenges, they were identified from a broad and detailed bibliographic research in the main knowledge bases and on the websites of the main scientific publishers, which means that they represent the vision of researchers who publish on the topic. Furthermore, the fact that they are not linked to the reality of a particular country suggests that they can provide important insights for improving drainage systems in all countries. However, this work has the typical limitation of studies based on bibliographic research to support their analyses. Therefore, although we have carried out an extensive and detailed literature search, there is always a risk that a relevant article has not been included;

(b) Regarding the main challenges, can they be considered the most important for cities in all countries? We believe that the set of main challenges must be interpreted according to the reality of each country. How the city is perceived and appropriated by society is influenced by the context in which the cities of each country are inserted since they have characteristics that differentiate them, such as government profile, socio-environmental culture, and financing capacity Guedes et al. [50]. Although this research was limited to assessments of Brazilian respondents, which makes generalizations have to consider local realities, it is important to emphasize that the realities and characteristics of Brazilian cities are present, to a greater or lesser extent, in most developing and underdeveloped countries. However, we emphasize that research based on expert evaluation has some degree of subjectivity due to the evaluator's interpretation of what is being evaluated.

Finally, we highlight that several authors argue that a wide range of actors should be involved in the planning and implementing of urban drainage systems, including decision-makers, service companies, society, universities, and investors [55]. However, in many developing and underdeveloped countries, there are political and stakeholder articulation difficulties in developing a comprehensive view of the drainage system, which makes actions unconnected and of low impact to improve the effectiveness of the drainage system drainage.

5. Conclusions

In a world with unprecedented urbanization and population growth, urban drainage systems are subject to challenges that make it difficult to properly function.

Based on extensive and detailed bibliographic research, we identified 15 challenges for improving urban drainage systems 6 of which were considered the most important by professionals in the concerned field. The survey results confirmed the authors' view of the studies that supported this work since all the challenges were evaluated as important by the respondents. It is important to emphasize that the challenges identified enhance each other.

By exploring the concepts related to the challenges and their degree of relevance, this work helps designers start to incorporate new practices into the traditional way of designing drainage systems, especially those related to improving the sustainability and effectiveness of the system. Concerning decision-makers, this work contributes to the decision-making process on which system characteristics and variables should be prioritized. Finally, concerning the population, this work contributes to improving quality of life since more effective sanitation systems generate several benefits, such as reducing the incidence of waterborne diseases and reducing the occurrences of human losses and property damage.

Given the findings of this work, some recommendations are important. As for policymakers, they must attribute higher importance to aspects related to the urban drainage system in elaborating policies that translate into legislation, norms, and management actions. It is important to bear in mind that the dynamics of city expansion are intrinsically related to the vulnerability of urban areas. In developing and underdeveloped countries, a significant portion of the urban population lives in informal settlements, with poor drainage as one of their common problems. Policymakers need to include policies that include these settlements in master plans. It implies the need to establish higher-quality public policies that enable the inclusion of resources destined for investments in the improvement and expansion of drainage systems in municipal budgets. The infrastructure of cities is a key point for us to think about Smart and Sustainable Cities. It is also important to highlight that municipal administrations strongly depend on local policies to manage projects, actions, and services in favor of their communities.

It is also important for policymakers to discuss new mechanisms for financing and reducing costs for urban drainage systems, such as, for example, the concession of services to private companies or the so-called public-private partnerships (P.P.P.s). In Brazil, for example, many municipalities delegate the water supply and sewage collection systems to private companies, with the sewage rate calculated based on the amount of water consumed. However, drainage in territories is a local development problem that continues to be a major challenge for many cities in underdeveloped and developing countries.

Projects can be made possible with access to international structuring investments and multilateral organizations, such as the Inter-American Development Bank (I.A.D.B.), Development Bank of Latin America (C.A.F.), and other funding sources for achieving the Sustainable Development Goal of the United Nations Agenda 2030.

Regarding designers, they need to improve the traditional approach to urban drainage systems design. It demands a more holistic view that considers new variables that make the solutions viable and collaborate to improve the system's performance and the extension of its benefits.

It is important to point out that many designers, mainly those who work in the technical departments of municipal bodies, still have a traditional view that inhibits the interaction between drainage systems and between them and the environment and the population.

The population is the primary beneficiary of projects to improve urban drainage, as they help cities to provide more and more quality of life and dignity to citizens. The six challenges considered most important show the importance of engaging the population. The population must understand how their behavior benefits or harms drainage systems. The behavioral aspects are intrinsically related to the inadequate functioning of drainage infrastructure. For example, the clogging of storm drains by garbage and material from landslides, caused by dumping garbage in inappropriate places, increases the need for system maintenance and costs. How the population interacts with the drainage system is influenced by many factors, such as social, demographic, cultural, political, and educational ones. Understanding this context by decision-makers is essential for short-term actions to enhance communities' contribution to improving drainage systems, such as awareness campaigns and programs.

Further studies must address in more detail the consequences of the challenges identified in this work and new mechanisms that make it possible to mitigate these impacts. It is also important that further studies address how each challenge enhances the others. It will enable decision-makers to direct their efforts toward the most effective actions in a resource shortage scenario.

In the context of the scarcity of resources experienced by many countries, we hope that the results of this work can help decision-makers and policymakers to prioritize their efforts.

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