UNIVERSIDADE DE LISBOA

INSTITUTO SUPERIOR TÉCNICO

# Analysis of the paradigm shift in urban stormwater management: political, institutional, regulatory, public health, and economic aspects

Carlos Augusto Furtado de Oliveira Novaes

**Supervisor: Doctor Rui Domingos Ribeiro da Cunha Marques**

**Thesis approved in public session to obtain the PhD Degree in Territorial Engineering and Spatial Planning**

**Jury final classification: Pass with distinction**

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**2022**

To my brother Alvaro Novaes

# Declaration

I declare that this document is an original work of my own and that it fulfils all the requirements of the Code of Conduct and Good Practices of the University of Lisbon.

# Acknowledgments

The thesis was a job I gave myself without knowing what would happen. I was surprised a few times, the biggest one being during the pandemic, when I thought it would all be over, but there are people. They are really the great surprise of life. There have been many, and to them, I dedicate all my work. Known and unknown, they hold out their hands and help us to keep going. To them goes all my gratitude and the certainty that with them I have an unpayable debt, I owe my life.

It is impossible to know all their names, I will mention some thinking of all the others without ordering them, because they all extended their hands to me, each one in his or her own way.

To Professor Rui Marques, the advisor who always motivated me with his words of encouragement and who has an admirable and incessant way of working non-stop. I thank you not only for the guidance, but for the example that it is worth persisting so that results can happen.

To the teachers, from there, in Brazil, and from here, in Portugal, for the good reception and surprising way of making knowledge available. I know how important this is. I thank all the Professors, you are the soul of the University: Rui Oliveira and Diogo Fereira (multivariate Statistics); José Saldanha Matos and Filipa Ferreira(sanitation); Jorge Gonçalves, Miguel Amado, João Levy and Nunes da Silva (urban studies); Rosário Macário (methodology).

Still, in Portugal, I would like to thank Francisco Silva Pinto, with whom I had the satisfaction of being able to count for the statistical analyses and activities that generated the chapter on health.

To Patrícia Nunes, I thank you for the support and example in the kind and patiently tireless treatment that you dedicate to all those who seek you at IST. You make all the difference.

In Brazil, I thank Guilherme Godoi from the Ministry of Mines and Energy, for the incentive given to me to go ahead and apply for a Ph.D. in Lisbon. To Marcos Helano Fernandes Montenegro, who besides being a friend, always brings intelligent suggestions.

I received contributions of all kinds, personal, work, and others. Some without knowing it, friends from Lisbon, Brazil, Mozambique, Syria, Germany, Italy, China, the USA, and many other places, with whom I interacted, I thank them all.

It is impossible to forget the people who made my return to Brazil no more difficult than it was at the beginning of the pandemic. I will always remember the doctors and the Air France team who assisted me in Paris and all the support they gave me and, from a distance, my son Marco Aurélio, my friend Marcelo Motta Veiga and my brother Álvaro Novaes, whose example, wisdom and international experience are unparalleled. You made sure that I arrived in São Luis "safe and sound" and could continue with this work. What you have done is priceless.

In São Luis, I owe everything to my wife, who welcomed me and continued to support me in those uncertain days, and encouraged me to go on with the work. Thank you for becoming a little giant supporting me.

The result of this work is much more from all of you and for you.

People are the reason for everything and make that any effort worthwhile, thank you all.

# Resumo

Os serviços urbanos de drenagem e gestão de águas pluviais são essenciais para a vida nas cidades e desde que estas se constituíram como locais de encontro e transação entre as pessoas, a urbe tem lidado de diversas formas com as precipitações. Conforme aumenta o número de pessoas cresce a complexidade da infraestrutura necessária para atender às necessidades sociais, económicas e ambientais nos territórios.

A gestão igualmente se complexifica e requer formas variadas de lidar com os sistemas de drenagem e gestão de águas pluviais, acompanhadas pelos custos associados a cada opção feita. Estas requerem a consideração cada vez maior de itens antes desprezados, por desconhecimento ou desconsideração, como são a poluição e a prevenção dos eventos extremos de escassez e abundancia de água, respetivamente, além das externalidades.

A evolução da humanidade, sob todos os aspetos, tem sido determinante dos problemas, mas igualmente das soluções apresentadas e para estas a tecnologia e o conhecimento têm se feito presentes como contribuintes da melhoria da gestão dos serviços urbanos.

O incessante crescimento demográfico e físico das cidades, aliado a todo tipo de mudança, das quais as alterações climáticas aparecem como principais determinantes do modo de vida a que os citadinos devem se submeter, tem feito com que as instituições e estruturas organizacionais sejam colocadas a prova requerendo, não muito raramente, a criação de outras, mais adaptadas à nova realidade.

Aspetos sociais, económicos e ambientais mostram-se diferentes em qualidade e magnitude, exigindo uma mudança de paradigma, consubstanciada em diversos aspetos como a consideração da água pluvial como recurso útil ao funcionamento urbano e não mais como transtorno à vida e a saúde dos habitantes da urbe. Assim, ao invés de afastá-la o mais rapidamente, a mentalidade recente aponta para as mais diversas formas de utilizá-la fazendo com que a sua convivência se estenda pelo maior tempo possível, para que se possam extrair benefícios.

Este estudo visa abordar esta mudança de paradigma, ainda incompleta e, portanto, em andamento, de forma a permitir que por meio da análise de várias matérias e exemplos, contando sobretudo com a reflexão crítica sobre estes, possa ser dada relevante contribuição ao desenvolvimento do assunto que, não tem sido enfocado com a intensidade que se entende necessária em função da importância e dos efeitos que produz sobre a vida urbana.

Assim, sem esgotar o assunto, após uma breve revisão bibliográfica, trata-se de aspetos políticos, institucionais e regulatórios (PIR) envolvidos na mudança de paradigma, e segue-se com o estudo da Inter-relação entre a drenagem urbana e a saúde pública, utilizando-se como abordagem o estudo de caso da Dengue, Chikungunya e Zika no Brasil. Em seguida são analisadas formas de materializar o suporte econômico e financeiro aos sistemas de gestão das águas pluviais urbanas, exemplificando-se com o estudo de caso de aplicação das Stormwater Utilities nos EUA e encerra-se a análise por meio da apresentação de exemplos, existentes em diversos países, da participação privada no setor (PSP) como um dos mecanismos utilizados para a mudança.

Palavras chave: Gestão das águas pluviais urbanas, Governança urbana em transição, Mudança sócio-econômica-institucional, Política Pública, Regulação dos serviços públicos, Saúde Pública

# Abstract

Urban stormwater drainage and management services are essential for city life and since cities have been places where people meet and transact, the city has dealt with rainfall in a variety of ways. As the number of people increases so does the complexity of infrastructure required to meet the social, economic, and environmental demands of the territories.

Management also becomes more complex and requires different ways of dealing with stormwater drainage and management systems accompanied by the costs associated with each option. These require the increasing consideration of items that were previously overlooked due to ignorance or disregard, such as pollution and the prevention of extreme events of water scarcity and abundance, respectively, as well as externalities.

The evolution of mankind, in all aspects, has been a determinant of the problems, but also of the solutions presented and for these, technology and knowledge have been present as contributors to the improvement of urban services management.

The incessant demographic and physical growth of cities, combined with all kinds of changes, of which climate change appears as the main determinants of the way of life to which city dwellers must submit, has caused institutions and organizational structures to be put to the test, requiring, not infrequently, the creation of others, better adapted to the new reality.

Social, economic, and environmental aspects are different in quality and magnitude, requiring a paradigm shift, embodied in various aspects such as the consideration of stormwater as a useful resource for urban functioning and no longer as a nuisance to life and health of urban inhabitants. Thus, instead of driving it away as quickly as possible, the recent mentality points to the most diverse ways of using it, making its coexistence extend for as long as possible, so that benefits can be extracted.

This study aims to address this paradigm shift, still incomplete and therefore in progress, so that through the analysis of various aspects and examples, relying mainly on critical reflection on these, it can be given relevant contribution to the development of the subject that has not been focused with the intensity understood as necessary due to the importance and effects it produces on urban life.

Thus, without exhausting the subject, after a brief literature review, the political, institutional and regulatory aspects (PIR) involved in the paradigm shift are addressed, followed by a study of the interrelationship between urban drainage and public health, using the case study of Dengue, Chikungunya, and Zika in Brazil as an approach. This is followed by an analysis of ways in which economic and financial support for urban stormwater management systems can be provided, exemplified by the case study on the application of Stormwater Utilities in the USA, and concludes with a presentation of examples of private sector participation (PSP) as one of the mechanisms used for change in several countries.

Keywords: Public policy, Public health, socio-economic-institutional shift, Stormwater management, Urban governance transition, Utility services regulation

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| | |
|---|---|
| **AASA** | Águas Argentinas SA |
| **ABC** | Saint André, Bernardo and Caetano Cities Region in São Paulo State |
| **ABRELPE** | Public Cleaning and Special Wastes Enterprises Brazilian Association |
| **ACA** | Automated Content Analysis |
| **ADASA** | Water and Power Regulatory Agency |
| **AI** | Impervious Area |
| **ANA** | National Agency for Water and Wastewater |
| **ARSESP** | Water and Energy Regulatory Agency of São Paulo State |
| **ASR** | Aquifer Storage and Recovery |
| **ASTR** | Aquifer Storage Transfer Recovery |
| **Ats** | Alternative Techniques |
| **AUD** | Australian Dolar |
| **BA** | Bahia State |
| **BMP's** | Best Management Practices |
| **CD** | Canadian Dollar |
| **CEDAE** | Water and Sewage Company of Rio de Janeiro State |
| **CEE** | Council of European Communities |
| **CHIKV** | Chikungunya Virus |
| **CIRIA** | Construction Industry Research and Information Association |
| **COFINS** | Contribution for the Financing of Social Security |
| **COVID-19** | Coronavirus disease 2019 |
| **CRCWSC** | Cooperative Research Centre for Water Sensitive Cities |
| **CT** | Connecticut |
| **CT's** | Compensatory Techniques |
| **CWA** | Clean Water Act |
| **DAPS** | Disease Associated with Poor Sanitation |
| **DATASUS** | Information Technology Department of the Public Health Care System SUS |
| **DENV** | Dengue Virus |
| **DER** | State Highways Department |
| **DWI** | Drinking Water Inspectorate |
| **EA** | Environment Agency |
| **ECSA** | East-Central-South- African |
| **EFAB** | Environmental Financial Advisory Board |
| **EPA** | Environment Protection Agency |
| **ERSAR** | Water and Waste Services Regulatory Authority |
| **ERU** | Equivalent Residential Unit |
| **ESC** | Essential Services Commission |
| **FACA** | Federal Advisory Committee Act |
| **FD** | Federal District |
| **FDs** | Floods Directives |

| | |
|---|---|
| **FMSAI** | Municipal Environment Sanitation and Infrastructure Fund |
| **GDP** | Gross Deep Product |
| **GEG** | Good Enough Governance |
| **GI** | Green Infrastructures |
| **GINI** | GINI Index |
| **GIS** | Geographical Information System |
| **HCP** | Habitat Conservation Plan |
| **IBGE** | Geography and Statistic Brazilian Institute |
| **IDH** | Human Development Index |
| **IPART** | Independent Pricing and Regulator Tribunal |
| **IRBM** | Integrated River Basin Management |
| **ISO** | International Organization for Standardization |
| **ISO 14001** | Environment Management System Standards |
| **ISO 9001** | Quality Management Systems Standards |
| **IWRM** | Integrated Water Resources Management |
| **KC's** | Kansas City's |
| **LA** | Louisiana |
| **LID** | Low Impact Development |
| **LTCP** | Long Term Control Program |
| **MAYV** | Mayaro Virus |
| **MEP** | Maximum Extent Practicable |
| **MHURD** | Ministry of Housing and Urban-Rural Development |
| **MS** | Mississippi |
| **MS4** | Municipal Separate Storm Sewer System |
| **NDRC** | National Development and Reform Commission |
| **NGOs** | Non-Governmental Organizations |
| **NJ** | New Jersey |
| **NOVACAP** | Urbanization Company of New Capital |
| **NPDES** | National Pollutant Discharge Elimination System |
| **NY** | New York |
| **O & M** | Operations and Maintenance |
| **OECD** | Organization for Economic Co-operation and Development |
| **OFWAT** | Office of Water Services |
| **PASEP** | Public Servant's Wealth Formation Program |
| **PDDU** | Urban Stormwater Master Plan |
| **PENSAARP 2030** | Water Supply, Wastewater and Stormwater Strategic Management Sector Plan 2030 |
| **PGDL** | Lisbon General Drainage Plan |
| **PIR** | Policies, Institutions and Regulation |
| **PLANSAB** | National Plan of Basic Sanitation |
| **PPPs** | Public-Private Partnerships |
| **PRISMA-P** | Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Protocols |
| **PRODES** | Basin Restoration Program |

| | |
|---|---|
| **PSBDF** | Federal District Basic Water and Sanitation Plan |
| **PSP** | Private Sector Participation |
| **REF** | Residential Equivalent Factor |
| **RJ** | Rio de Janeiro State |
| **SABESP** | Water & Basic Sanitation Company of São Paulo State |
| **SARS-COV2** | Severe Acute Respiratory Syndrome Coronavirus 2 |
| **SCI** | Sponge Cities Initiative |
| **SCP** | Sponge Cities Program |
| **SCS** | Soil Conservation Service |
| **SCT** | Source Control Techniques |
| **SDG** | Sustainable Development Goal |
| **SDG6** | Sustainable Development Goal 6 |
| **SE** | Southern Australia |
| **SGP** | State General Permits |
| **SNIS** | National Water and Sanitation Information System |
| **SP** | São Paulo State |
| **SS** | Sewerage System |
| **SSOs** | Sanitary System Overflows |
| **SSWM** | Sustainable Stormwater Management |
| **SuDS** | Sustainable Drainage Systems |
| **SUDS** | Sustainable Urban Drainage System |
| **SUS** | Single Health Care System |
| **SWBU** | Salisbury Water Business Unit |
| **SWMB** | Salisbury Water Business Management Board |
| **SWOT** | Strengths Weaknesses Opportunities and Threats |
| **SWUs** | Stormwater Utilities |
| **TFUFPSI** | Task Force on Urban Flooding Problem and Solution Investigation |
| **TMDL** | Total Maximum Daily Load |
| **U.S.** | United States |
| **UK** | United Kingdom |
| **UN** | United Nations |
| **USD** | United States Dollar |
| **USA** | United States of America |
| **USEPA** | The United States Environment Protection Agency |
| **UWWD** | Urban Wastewater Collection and Treatment Directive |
| **WFD** | Water Framework Directive |
| **WHO** | World Health Organization |
| **WNV** | West Nile Virus |
| **WQA** | Water Quality Act |
| **WS** | Water Supply |
| **WSC** | Water Sensitive City |
| **WSS** | Water and Sanitation Services |
| **WSUD** | Water Sensitive Urban Design |
| **Wtc** | Wastewater collected |

| | |
|---|---|
| **WTP** | Willingness to Pay |
| **Wtt** | Wastewater treated |
| **YFV** | Yellow Fever Virus |
| **ZIKV** | Zika Virus |

# 1. INTRODUCTION

## 1.1 Background

The urban public services sector of stormwater drainage and management, although important for the functioning of cities, receives little attention, partly because of its low physical visibility because traditional solutions usually involve buried structures and pipes, and partly the due to lack of public knowledge. Physical visibility, however, is more present at times when the infrastructure is in demand, i.e., during rainy seasons, especially when extreme events occur, such as urban flooding. On these occasions, technical, political, institutional, and operational issues also become more visible, calling into question the structure of the holders, the municipalities responsible for providing services. Usually, interventions are carried out at specific points (in time and space), followed by a return to the previous status quo and waiting for the next opportunity to act, in a reactive posture to events. This kind of action to address urban stormwater problems has been recurrent and is at best inefficient, brings a high degree of uncertainty and leads to waste of resources and even corruption.

However, there is a growing realization that technical issues alone are not sufficient for the provision of services, as solutions are subject to political decisions, must be in accordance with institutions and duly regulated according to the requirements set out in contractual clauses agreed between owners and providers. To this understanding is added a reality in which a multiplicity of actors operates in various subjects, multidisciplinary and interconnected, requiring solutions other than those that are focused on command and control and subjected to the flavor of events and the will of the political decision-makers of the moment.

The complexity of these services takes away the interest of even scholars of some other specific issues, but which are related to them, such as urban planners, those responsible for health and sanitation, for the ways of building and distributing housing in cities, for draining their waters and even for moving around within them. The same happens concerning the economic issues, income distribution, land tenure, or taxation, collection and regulation of tax and tariffs for these services, so that when the literature addresses them it is in a fragmented way, leaving gaps to be filled.

The fragmentation of knowledge hinders the understanding of problems involving multidisciplinarity, as is the case of urban issues, absent, for instance, in the training of new professionals who, coming out of engineering schools, hardly understand the approach of the theme in its social and economic aspects. Restricted to the production of solutions focusing on the hydraulic and structural performance of buried pipes and open channels. At best they manage to pay attention to sanitary issues, but always linked to the removal of water as quickly as possible, treating it as a problem to be eliminated. In other disciplines, such as architecture and urbanism, the vision is not usually very different, taking care of urban forms and trying to ensure that the function of infrastructures, as far as possible, can accompany them. From an economic point of view, the implementation of new neighborhoods usually follows a return on investment approach and when this does not occur, as is the case of favelas and slums, which are born without following any planning logic or any other logic that may be taught at university, they are treated as a social problem, leaving the necessary infrastructure to be implemented later, that is, at the will of political interests. Thus, the provision of services is subject to the political will to provide resources, which does not usually occur spontaneously, making these territories dependent on public interventions, political calendars, facilitating corruption and hindering universalization (Narzetti & Marques, 2021).

Stormwater drainage is part of this context, it does not escape the prevailing logic, and without proper institutionalization, especially in places of insufficient democratic practice, with little participation and no sharing of decisions among all stakeholders, it remains on the margins of urban development reflecting the weakness of institutions and structures in charge of city management. In the absence of specific policies and under the cloak of non-existent controls, whether due to a lack of formalized regulation by contracts and agencies, or to a lack of social control by civil society, countless gaps remain and almost everything remains to be done to have an organized sector.

The result of the predominance of this status quo is visible in the poor working conditions of the drainage systems. In most places overflows occur from the networks, unitary or separating, for various reasons, including physical inability to conduct flows with new volumes and peaks, arising from climate change. The issue is not only about quantitative aspects, because the diffuse pollution brought by the rains ends up being concentrated in the receiving bodies, with impacts on environmental quality. Many times, when the physical structure of the systems is well dimensioned hydraulically, management strategies are not designed, which could be sufficient to solve problems arising from precipitation, as is the case of countless operation and maintenance issues, such as cleaning and unblocking retention and detention networks and reservoirs that present themselves with their reduced capacities when events that demand them occur.

The pollution, carried mainly during the so-called "first flow", is also an example of an aspect that depends on the management strategy, which may determine, for example, its forwarding or reservation for treatment in adequate facilities in a decentralized or centralized manner.

The various solutions, however, go through a change in mentality and involve multiple aspects, which can be translated by the need for a broad paradigm shift. This change begins with the way of understanding water in cities, which is no longer seen as a curse, but as an important resource for urban well-being. Thus, instead of creating mechanisms and instruments to keep it away from cities, it requires others that can make it remain as long as possible in the urban environment so that better uses can be made for it.

The consequences of this change make rainwater a valuable asset and thus the places where it falls have a new status, creating green gardens on building roofs, as well as various devices such as storage reservoirs for various uses such as toilet flushing or irrigation of public and private green areas. Their use enables not only the reduction of water supply volumes, saving natural resources, but also the reduction of WSS expenses and/or the receipt of subsidies as incentives for disconnection from public stormwater drainage systems in places where runoff reduction policies are established.

Policies with strong economic appeals produce environmental and social effects by facilitating, through pricing, subsidies and other mechanisms, incentives for the localized consumption of precipitated water, reducing the use of implemented infrastructure and reducing the costs of their maintenance, expansion and new implementation. In many places, they are also able to facilitate the understanding of the role of water, its importance and capacity to mitigate nuisances such as heat islands, water scarcity and increase urban well-being, provide for the implementation of amenities and make the depollution of the receiving media and the reduction of flooding a reality.

A good policy design, according to local peculiarities, aligned with the institutionalization of services and sources of revenue that sustain them financially and continuously, tuned to participatory organizational structures and appropriate regulation, can attract PSP, and start to rely on resources and skills previously unavailable in the traditional paradigm, centralized and focused on command and control, where there was no participation of a large number of stakeholders.

The challenges posed by reality, which has been changing for some decades, mainly due to urban demographic expansion, ageing infrastructures, climate change and growing ecological awareness, to be made compatible with human development expectations, expressed in goals such as sustainable development (SDGs), however, require the extension of the paradigm shift underway. The decentralization of solutions, with the participation of all actors, public, private, and civil society, is a feasible alternative, even though it demands increasing complexity in the solutions and a lot of work, but potentially brings greater welfare to human society.

The extent of change means not only reproducing the successful experiences of partnerships in some places and in other sectors, such as electricity and telecommunications, in which PSP is a significant, if not total, part of these services. One of the characteristics verified in the urban drainage sector is that the impermeable public part of the cities, represented by streets, squares, and other spaces affected by the public power represents about 50% of the total, making it mandatory for the solutions to be public and private, i.e., involve all actors.

Thus, the simple idea of replacing management done by a structure, in principle less efficient, such as the public sector, with a more efficient one, in principle the private sector, as happens in many cases, brings challenges to the production of good results, for the simple fact that the replacement of one structure by another in 100% of urban drainage services, seems a practically impossible alternative, which constitutes an issue to be better studied. This way, the doubt remains as to the optimal percentage to be accepted to have a satisfactorily acceptable performance, which leads to a question of prioritization and choices.

In each location, specific conditions form the contours of the issue and, in Brazil, it is not different, which made us produce some analyses based on available health information, specifically considering cases of Dengue, Chikungunya, and Zika, exemplifying the interface between drainage, urban water and public health of the population and, more recently, with the discussion of some aspects related to the presence of the epidemic of COVID-19. The subject is multidisciplinary and cannot be treated in isolation since it also involves multiple actors and reveals multisectoral implications.

## 1.2 Knowledge gap

To solve the challenges posed by the context described, it is necessary to identify which elements, policies, institutions, or forms of action are present but must be changed, or, on the contrary, if they are absent, they should be included, removing obstacles so that long-lasting solutions can be obtained, not punctual ones, and which avoid corruption, waste of resources and many other evils that, although difficult to measure, deserve attention so that good results can be achieved.

Like most of the problems present in cities, regardless of their degree of development and organization, here too, these are choices to be made. From the point of view of the technical efficiency of the performance of the systems, the basis may lie in indicators and technical criteria, with statistical support in field data, however, these choices are usually different from those made by decision-makers based on purely socio-political-electoral or even institutional points of view, but forged within the logic of a traditional centralized paradigm with a command and control focus.

This thesis aims at the challenge of bringing to discussion and addressing some aspects related to the paradigm shift, whose absence or little presence, translates into gaps not only in the literature but also in the proper provision of urban stormwater drainage and management services. This change, known by different names depending on its origin, is not new and, although it is widely used, its presence is still small when compared to the universe of cities and the little information regarding evaluations and performance comparison. The approaches, known as Best Management Practices (BMP) or Low Impact Development (LID) in the USA and New Zealand, Sustainable Urban Drainage Systems (SUDS) in the UK, Water Sensitive Urban Design (WSUD) in Australia, Alternative Techniques (Ats) or compensatory techniques (CT's) in France and Brazil, Sponge Cities Projects (SCP) in China, still await standardization of concepts even in the literature itself, according to Fletcher et al. (2015).

Without the pretension of exhausting the subject, we seek, through the presentation of some ways through which, in several cities, success has been achieved in the equation of issues related to the sector, relating them to the broader context, placing them in connection with other sectors, such as public health, showing the breadth and depth that can be achieved by the solution of issues that, when seen in isolation, do not seem to go beyond the sector and have the scope that actually has.

The gaps are of various types, technical, information and knowledge, political, institutional, regulatory, organizational, and interconnectivity with other sectors, but mainly in management and mentality. The latter is rooted in an inertia which can be characterized, according to neoinstitutionalist theory, as a case of institutional inertia dependent on the trajectory traditionally followed up to now, but which has led us to a situation of low performance. In some countries, as is the case in Brazil, the result can be translated into great disorganization, low institutionality, and other factors that have resulted in various problems, including some catastrophic events, such as those recently repeated in the historic city of Petropolis, in the state of Rio de Janeiro, but which are almost always attributed solely to natural causes, forgetting the other factors.

However, it is necessary here to take care not only of the diagnosis, but also of the presentation of alternatives to face all these challenges and gaps which, due to their magnitude, quantity, low availability of resources and, in many places, having little public understanding of the subject, a fact that affects the acceptability of proposals, especially those that intend to have economic support from users and taxpayers, is a not easy task. The difficulty in implementing some of the alternatives, such as Stormwater Utilities in the USA, which, despite having achieved success in several places, are still not the most accepted solution, exemplifies the problem around the economic support of an activity that, in that country, is focused on meeting the demands of legislation that seeks the elimination of pollution and other consequences of urban runoff.

PSP, seen as an alternative for the development of the sector, is presented in different forms that aim at filling the existing gap in resources and improving management, by seeking to take advantage of the capacity and experience existing in the private sector. The contribution of resources from the private sector may occur by means of several options, of which the best known are the traditional concessions or PPPs arrangements, which in Brazil have two modalities called administrative or sponsored concessions, respectively counting on remuneration using payments by the public sector or by means of a composition between tariffs collected from users and contributions made from the public budget. Other modalities are privatization or the sale of participations, through which the total control or participation are alienated to the private sector, for example, through the launching of shares of public companies made available to the market. Thus, the sources of revenue are often tied to the contribution of resources made solely by private actors, and sometimes in a combined manner, i.e., part public and part private.

Despite the use of varied mechanisms, there are still no predominant forms, but in some countries, of large dimensions, such as the USA and Canada, there are some trends, such as the Stormwater Utilities, while in others such as China alternatives are still being sought, such as PPPs in SCPs or in Brazil, where there are expectations that PSP will occur on a large scale, without, however, there being, so far, many concrete initiatives, but with the proposition in the legislation of incentives to PSP.

### 1.3 Research questions

Why are the available techniques and organizational structures insufficient to provide the efficient performance of systems in charge of urban stormwater management?

What are the key determinants involved in the paradigm shift underway and contributing to the materialization of this transition?

How do the main physical and other constraints involved in the transition behave and why are they relevant?

In the territory where drainage systems function, interaction with other important systems, such as of health, can occur in what way?

What are the existing and possible ways to economically support urban drainage and stormwater management systems, including considering stormwater as a useful resource?

### 1.4 Research objectives

Having as its main objective to answer the five initial questions, by visiting the aspects involved in the paradigm change underway in the sector, this investigation seeks to face, with answers, the challenge of how to deepen the understanding of what is behind the mindset and actions which can favor and accelerate the change, gaining efficiency, greater participation of society and especially performance results of services. The final result is to present contributions for better stormwater related decisions, based on the findings, on the experiences of the cases analysed, and on critical analysis, materialized in the recommendations presented as results.

The study aimed, based on bibliography, case study verification, and experiences, to problematize aspects of importance that could contribute to the debate and discussion, seeking to provide subsidies for the evolution of knowledge in the sector, systematizing findings and presenting paths that can be used to improve performance and practices existing today in the sector.

Disregarding as a premise the possibility of standardized or single solutions as an answer to a myriad of questions, but at the same time believing that there is a general background to all of them, the study was developed with also the objective to find it and analyze what exists and what is missing to materialize what is conventionally called a paradigm shift in the stormwater management sector. Changes, however, only make sense if what is intended is performance improvement, whether through greater efficiency in the use of resources, improved quality of the environment, management, and social welfare, or simultaneously all of these aspects. Thus, analyzing stormwater systems management performance aspects is another of the objectives of the study, but with reflections that can easily be extrapolated to other public services.

Besides these, another objective was to explore, in an unprecedented way, an ever present but little analyzed relationship between the reflexes of urban infrastructure, or its absence, in other sectors, as is the case of Public Health. To fulfill this objective, we focused on the occurrences of Dengue, Chikungunya, and Zika epidemics in Brazil.

The controversial private participation in matters of public responsibility and ownership was treated as another objective of the study. The presence of the private sector in important services such as telecommunications, energy, oil, gas, and WSS has many studies, but the same does not occur with regard to stormwater management, there being a large gap in this approach. The objective is assessing economic aspects linked to the economic sustainability of the sector. One specific focus is on the evaluation of economic structuring and management through Stormwater Utilities and the other, more general, is to present and reflect on the various forms of PSP in urban stormwater drainage and management. The structuring of the thesis traces a path that leads to a gradual understanding of the present challenges. Starts from the conceptual approach of Policies, Institutions and Regulation, go through concrete examples, analyses general and specific aspects in different countries, making possible to define the current situation of the sector and its contradictions explicitly, end up by forming a general picture of the situation that allow the identification of the most important points of the paradigm shift.

### 1.5 Outline

This thesis is organized into ten chapters, including this first one with the introduction to the subject and the last one containing the recommendations.

In the seven central chapters, presented in figure 1.1 below, interrelated issues are addressed sequentially to allow the increasing understanding of the subject based on the proposed approach that starts from the identified gaps, i.e., from the aspects related to Policies, Institutions and Regulation.

Thus, we begin in chapter two with a hybrid literature review that encompasses texts published over four decades, from the 1980s to 2020, enabling the visualization of the growing importance of the Policy, Institutional and Regulation (PIR) tripod, especially in more recent years.

As of chapter three, the three subjects are developed, starting with the rules of the game, represented by formal and informal institutions, according to the neo institutionalist view, present in the work of Douglas North (1990) and the more recent concept of governance as presented by Tortajada (2010).

Chapter four is entirely dedicated to the interesting gap represented by the absence of policies that address the various aspects involved in the drainage issue and indicates not only their importance, but also their dependence on previous policies and the paths already taken, placing them in a logic loaded by inertia and path dependence as important conditioning factors of the changes to be made.

Chapter 5 concludes the presentation of the last item of the PIR tripod, i.e., the regulation of services, which complements policies and institutions by regulating, through incentives, the objectives set so that the proposed results can be achieved.

As of chapter six, more specific approaches are initiated by means of themes in which interdisciplinarity emerges making visible their relations and imbrications with other themes relevant to urban life, as is the case of health or its absence, which can be understood as the presence of diseases. The recent epidemics of Dengue, Chikungunya, and Zika, which recently occurred in Brazil, are addressed and correlated to the WSS infrastructures, demonstrating, through statistical analysis, some findings that corroborate the interfaces between the sectors of health and urban infrastructure.

Finally, some economic issues are studied, which motivate concerns due to the low availability of public resources for sectors considered not very visible, as it is the case here of stormwater management.

Chapter seven deals with Stormwater Utilities, originated in the USA, as a solution to meet the demands of increasingly severe regulations regarding diffuse pollution produced from urban stormwater runoff, and the few resources available in the places where they are generated. The key question, still without a definitive answer, contained in the statement that is also the title of the article, expresses well the problematic content of the chapter: "Stormwater Utilities: A Sustainable Answer to many questions".

Finishing the economic approach, chapter eight studies another question that still is a gap to be filled that, when correctly solved, may allow the economic sustainability of the sector, a fundamental issue for its performance: Private Sector Participation (PSP). Once again, the question is found in the chapter's title and demonstrates the uncertainties brought about by the existing gap is still to be equated: "Attracting the private sector to urban stormwater: a feasible task or just a pipe dream?"

The chapter nine presents the conclusions, findings, limitations encountered, and suggestions for further studies and finally the chapter ten brings the recommendations.

Figure 1.1 below presents the main body of the thesis, minus the introductory, concluding and recommendations chapters, emphasizing that all the themes of chapters' in picture 1.1 are part of texts submitted to various specialized journals, in the form of papers whose titles are presented in figure 1.1, next to each specific theme.

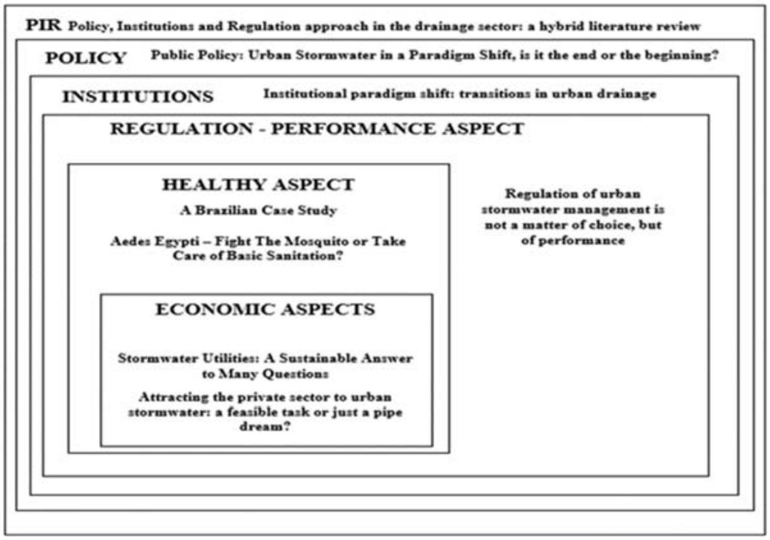


Figure 1.1 - The main themes of the thesis.

# 2. POLICY, INSTITUTIONS AND REGULATION APPROACH IN THE DRAINAGE SECTOR: A HYBRID LITERATURE REVIEW

This chapter was submitted to an international peer-reviewed journal.

## 2.1 Introduction

The existence and the lack or excess of water and its impacts on cities are well known to the population and reasonably relatively well studied by stakeholders, but the visible results say little about what is missing or what is at the root of the problems that lead to poor management in the drainage sector (Dhakal and Chevalier 2017). Sustainable drainage and adequate management of rainwater on urban land require a set of incentives based on appropriate public policies that, governed by well-regulated institutions, enable satisfactory results to be obtained. Allied to this tripod of policies, institutions and regulation (PIR) is the question of the resources required to achieve the objectives and, therefore, also the question of not only how to obtain funding to make the necessary investments feasible for the accomplishment of urban stormwater drainage and management actions but also how to institutionalize the provision of these services. Furthermore, the local enabling environment, including prevailing policies, governance frameworks and broad political economy factors, is determinant (Uijtewaal et al., 2018).

Although the concepts present in the PIR tripod may initially seem confusing, due to the fact that they are closely correlated, it is possible to situate them separately, especially to separate the incentives and barriers that exist for their operationalization as a tripod supporting service delivery systems.

Policies are the fruit of the perceptions of public decision-makers (agents of the executive and legislative branches of government) and private decision-makers (directors and managers) about the (not always) real problems of society. Institutions are the formal (laws, decrees and regulations) and informal (habits and customs) rules of the game, and regulations are responsible for enforcing the rules.

Thus, policies provide the guidelines, institutions provide the rules to be followed, and regulations control actions at all stages, from planning to execution. The incentives for actors on each side of the tripod may be different, but they must be aligned for actions to materialize. Lack of alignment between policies, rules to operationalize them and enforcement mechanisms leads to ineffectiveness and waste of resources, to say the least.

Therefore, integrated and aligned institutional interventions between PIR aspects can support more sustainable drainage service delivery. The issue is how to establish incentives for actors and organizations in terms of policies, institutional arrangements and regulatory structures, which will create a continuous motivation to make sustainability a reality in terms of access, quality of service, financial resources and environmental sustainability, allowing actors to fill existing gaps in the drainage sector (Mussmem et al., 2018).

The aim of this research is to observe how the subject involving policies, institutions and regulation (PIR), with regard to the drainage and management of urban stormwater, has been addressed by the literature. Analyzing the available publications since the 1980s, when these matters started to be investigated, allows us to identify the trends and best practices and the gaps in the literature, particularly the existing themes and approaches and those that are absent, requiring research and deepening of discussions in technical and academic circles.

For this purpose, a hybrid methodology to review the literature will be adopted. It will be structured into three phases, allowing a broad analysis of the evolution of the subject in the literature, over the last decades, a period in which there were major changes in urban environments with population growth and climate change, among others, generating pressures on urban systems and infrastructure, whose response is not always considered satisfactory in terms of the performance of drainage systems and stormwater urban management. In the first phase, through a quantitative survey of the articles, the areas, places and outlets with higher production were identified, which may be of greater concern for academies with the corresponding problems, even though a set of papers shows a great distribution of the topics of research. Therefore, a second phase was carried out to refine the articles found in the first phase (the elimination process) and to match them with the aims of the research. Finally, a third phase related to the detailed analysis of the articles was developed (the analysis process). This phase comprises a quantitative, semantic, and narrative analysis, allows identification of the main themes and their connections and is complemented by a conceptual map generated from these themes.

To the best of our knowledge, this is the first literature review article on the institutional and managerial issues of the drainage sector. Moreover, the contributions of this article are also based especially on communicating an essential perspective to scholars and decision makers as to the importance of the subject and the gaps in the literature, despite its importance for the development of the necessary actions in the drainage sector.

This chapter is comprised of five sections. In addition to this brief introduction, Section 2 describes the research methodology applied, and Section 3 displays the main results obtained. Then, Section 4 discusses the results and the main research areas, and Section 5 draws the conclusions and suggests future research.

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## 2.2 Research methodology

Usually, a literature review can provide information on the state of the art of a certain subject, contributing to those who are interested in the themes by starting from what is already known or even from what is unknown, but which requires more attention at certain times. This is the case for the subject of urban drainage and stormwater management, which requires reflection and exchange of experiences, due to its complex transdisciplinary nature and the absence in many cities of a clear institutionalization of services and establishment of responsibilities (Montenegro, 2017). Even with similar regulatory and institutional frameworks, there are places where drainage systems have good results and others where this is not the case.

In the absence or existence of little systematized information about management and especially about the incentives provided by the alignment of PIR, we took the challenge of carrying out a hybrid literature review, a combined method comprising the narrative and systematic quantitative review methods, supplemented by semantic network analysis that could bring to light what exists and illuminate paths to follow about what does not exist and that, therefore, needs to be completed through studies, analysis and reflections that can contribute to elucidating issues and pointing out solutions to urban drainage systems management with a focus on the PIR approach.

In this chapter, as mentioned, a hybrid methodology to review the literature was adopted following three phases: a search process, an elimination process, and an analysis process. Figure 2.1 presents, in a schematic way, the structure of the methodology used and its three phases.

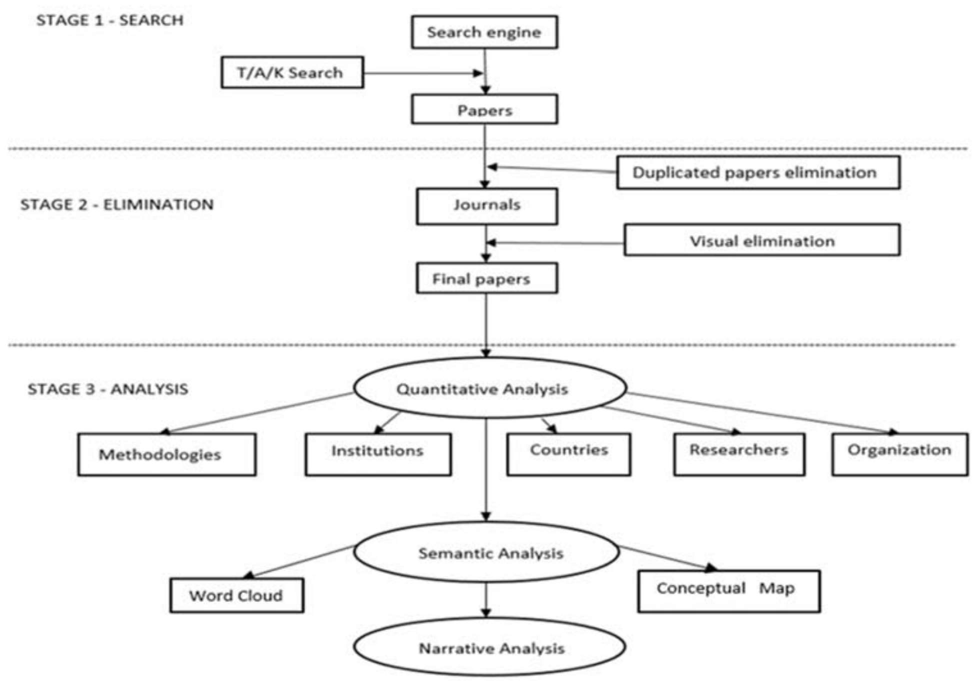


Figure 2.1 - Research framework (adapted from Ke et al. 2009 and Yu et al. 2018).

The search process was based on the titles, abstracts and keywords of the articles. The search codes used in the 9 searches carried out can be seen in Table A of the Appendix. Table 2.1 describes the structure and the three phases of the process and the results in terms of the numbers of documents selected, while Table 2.2 presents the key words with the corresponding numbers of documents obtained by the search. The review is also based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Protocols (PRISMA-P 2015) guidelines (Moher et al., 2010) adapted to the present study.

According to authors of this approach (Moher et al., 2015), PRISMA-P is 'a guideline to help authors prepare protocols for planned systematic reviews and meta-analyses that provide them with a minimum set of items to be included in the protocol and a protocol is intended to provide a rationale for the review and pre-planned methodological and analytic approach, prior to embarking on a review'. Therefore, in phase 1, the search engine Scopus was used to retrieve paper articles and reviews, and the selection criteria were the title, abstract and keywords, as mentioned. There were no time restrictions applied, and the language of the selected texts was English and Spanish. The subjects selected were limited to social, environmental, engineering, business and economic areas. Scopus is a successful search engine according to other authors and researchers because it allows an overview of the subjects and is the only one to present the number of citations (Tober, 2011), which can help in the choice of articles. This is why it was selected from among others, such as Google Scholar, Web of Science and SAGE Premier. With more than 25,100 titles from more than 5000 international publishers, Scopus is a source neutral abstract and citation database curated by independent subject matter experts and delivers a broad overview of the world's research outputs in many fields (Elsevier, 2020). The methodology has many risks of bias; for example, in the search stage, the keywords selected can carry some kind of bias; in the second stage, some papers that were not included can provide some interesting information; and finally, in the analysis stage, the automated content analysis (ACA), frequency based, can exclude some words and connections not highly visible to the automated software systems (Lupu et al., 2019).

The keywords related to the study were identified and grouped (three or four words in each group): institutions, policy, regulation, drainage, stormwater and rainwater.

Stage 2 considers the elimination of duplicated and non-relevant papers, the former by the automated Scopus combination process and the latter by a visual examination and this resulted first in 380 papers selected and finally 112 papers selected. Finally, stage 3, process analysis, contains three parts: systematic quantitative review, semantic analysis and narrative analysis.

Table 2.1 - Three-phase research framework based on titles, abstracts and keywords.

| Phase | Process description |
|---|---|
| 1<br>Search Process | Papers Search: Title/Abstract/keywords<br>Approach: Scopus; Results: **514** papers |
| 2<br>Elimination Process | Elimination Process: Duplicated papers<br>Approach: Scopus automated combination ("OR")<br>Results:**380** papers<br>ination Process: Non relevant papers to the research topic and non-relevant journals<br>Approach: Visual Examination<br>Results: **112** documents |
| 3<br>Analysis | Systematic Quantitative Review<br>Semantic Analysis (Word Cloud generator by Monkey Learn and Leximancer 5.0 automated tools)<br>Narrative analysis |

Table 2.2 - Results of phase 1 of the search process through the Scopus database.

| Search Number | Keywords | Results |
|---|---|---|
| 1 | Poli* Institut*Regul* Drainage | 24 |
| 2 | Poli* Institut*Regul* Stormwater | 17 |
| 3 | Poli* Institut*Regul* Rainwater | 9 |
| 4 | Poli* Regul* Rainwater | 41 |
| 5 | Poli* Regul* Stormwater | 115 |
| 6 | Poli* Regul* Drainage | 183 |
| 7 | Institut*Regul*Drainage | 62 |
| 8 | Institut*Regul*Stormwater | 39 |
| 9 | Institut*Regul*Rainwater | 24 |
| **Total** | | **514** |

Note: The use of *(wildcards) in Scopus allows to recovery word variations (e.g., "Regulation" and "Regulatory").

## 2.3 Results

### 2.3.1 Systematic quantitative review

#### 2.3.1.1 Publications distribution by time

The first stage of the quantitative systematic review was the analysis of the number of papers published per decade. The distribution of the 112 documents obtained, researched over a period of four decades, between the 1980s and 2020 is presented in Figure 2.2. The last day considered in the search was 31 December 2021. There has been a growing trend, particularly in recent years, which allows us to assume that there is an increase in interest in the subject. The first article published in 1980 with the title 'Overcontrol of urban runoff by park storage' provides a critical review of the "zero runoff increase" policy used by regulatory agencies in Canada and the U.S. Under the principle of "overcontrol", the reduction of post development flows to less than predevelopment flows to reduce the existing flooding in the major drainage systems of downstream areas was analyzed, and several projects and economic aspects were considered by the authors (Wisner and Kassem, 1980).

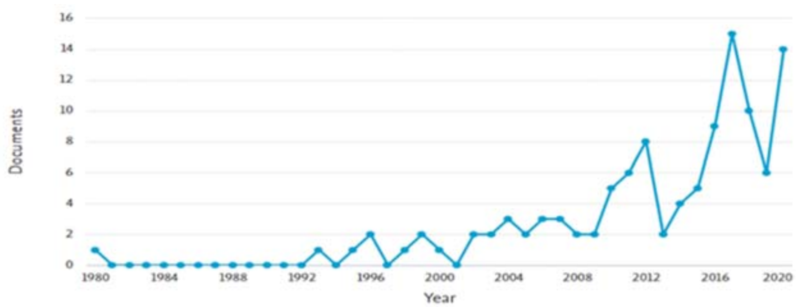


Figure 2.2 - Documents distributed by year of publication.

#### 2.3.1.2 Publications by subject area and journals

The subject areas are shown in Figure 2.3. The area with the highest number of papers is Environmental Science with 97, or 41.8% followed by Social Sciences with 49, or 21.1%, and Engineering with 25, or 10.8% of the total. Some of them are associated with different subject topics.

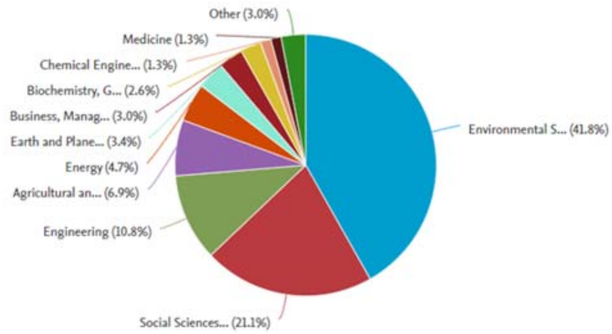


Figure 2.3 - Number for documents by paper subject area.

The top ten journals with the most articles or more than three articles are shown in Table 2.3 below. The Journal of Environmental Management and Water journals are the ones with more articles on the subject. In total, 73 journals published articles.

Table 2.3 - Number of papers by journal.

| | | |
|---|---|---|
| Journal of Environmental Management | Q1 | 6 |
| Water Switzerland | Q1 | 6 |
| Urban Water Journal | Q2 | 4 |
| Journal of Cleaner Production | Q1 | 4 |
| Journal of Water Resources Planning and Management | Q1 | 4 |
| Water Science and Technology | Q3 | 4 |
| Sustainability Switzerland | - | 3 |
| Journal of Hydrology | Q1 | 3 |
| Journal of The American Water Resources Association | Q1 | 3 |
| Landscape and Urban Planning | Q1 | 3 |
| Others (2 papers in each journal) | N/A | 18 |
| Others (1 paper in each journal) | N/A | 54 |
| **TOTAL** | | **112** |

#### 2.3.1.3 Publications by authors, organizations and countries

There is more than 1 author in many studies, which totals more than three hundred authors in the 112 documents found, or an average of more than 2.0 authors for each study in 73 journals. The most published author is J.B. Ellis from the Natural Environment Research Council in the UK with four publications as shown in Table 2.4.

Concerning the main author's affiliation, Table2.5 shows that 32.7% (64) of the total (196) authors are from twenty-eight organizations, most of all universities, and in twelve countries (Australia, Canada, China, Colombia, Germany, Israel, Italy, New Zealand, South Africa, Sweden, the UK and the USA), and nearly 25% of these 64 studies (16) were produced in Australia and 23.4% in the USA (15). Table 2.4 illustrates the author's score calculated according to the formula presented below and Table 2.8. The number of publications by country is shown in table 2.6.

Table 2.4 - Number of published studies by author and author's score.

| Authors | Studies | Author Scores |
|---|---|---|
| Ellis, J.B. | 4 | 2.09 |
| Brown, R.R. | 3 | 1.00 |
| Schimtt, T.G. | 3 | 1,94 |
| Butler, D. | 2 | 0,25 |
| Campisano, A. | 2 | 0,52 |
| Ciaponi, C. | 2 | 0,63 |
| Cook, S. | 2 | 0,38 |
| Deletic, A. | 2 | 0,24 |
| Duke, L.D. | 2 | 1.00 |
| Ettrich, N. | 2 | 0,42 |
| Hogue, T.S. | 2 | 0,47 |
| Iftekhar, M.S. | 2 | 0,36 |
| Kim, J.H. | 2 | 0,58 |
| Maksimovic, C. | 2 | 0,33 |
| Marsalek, J. | 2 | 0,51 |
| Matsler, A.M. | 2 | 0,68 |
| Papiri, S. | 2 | 0,64 |
| Petrucci, G. | 2 | 0,89 |
| Sharma, A.K. | 2 | 0,76 |
| Thomas, M. | 2 | 0,64 |
| Tjandraatmadja, G. | 2 | 0,25 |
| Todeschini, S. | 2 | 0,94 |
| Wong, T. | 2 | 0,48 |
| Zhu, D. | 2 | 0,72 |
| Others 136 authors | 136 | |
| **Total** | **188** | |

Table 2.5 - Publications affiliations and author's countries.

| Author's Affiliation | Country | Studies |
|---|---|---|
| Monash University | Australia | 6 |
| The University of Auckland | New Zealand | 2 |
| Seoul National University | South Korea | 2 |
| Middlesex University | UK | 3 |
| University of Melbourne | Australia | 3 |
| University of California, Los Angeles | USA | 3 |
| School of Ecosystem and Forest Science | Australia | 3 |
| Environment Canada | Canada | 2 |
| The University of Sheffield | UK | 2 |
| Arizona State University | USA | 2 |
| Purdue University | USA | 2 |
| Technische Universität Kaiserslautern | Germany | 2 |
| Università degli Studi di Catania | Italy | 2 |
| University of Oregon | USA | 2 |
| Colorado School of Mines | USA | 2 |
| Imperial College London | UK | 2 |
| Università degli Studi di Pavia | Italy | 2 |
| Institute of Ecosystem Studies | USA | 2 |
| Western Sydney University | Australia | 2 |
| Helmholtz Zentrum für Umweltforschung | Germany | 2 |

| | | |
|---|---|---|
| Chinese Academy of Sciences | China | 2 |
| Fraunhofer Institut Industrial Mathematics ITWM | Germany | 2 |
| Texas A&M University | USA | 2 |
| Technion – Israel Institute of Technology | Israel | 2 |
| Shangai Jiao Tong University | China | 2 |
| CSIRO Land and Water | Australia | 2 |
| University of Exeter | UK | 2 |
| Fundación Universidad de América | Colombia | 2 |
| Others (1 each one) | N/A | 132 |
| TOTAL | | **196** |

Table 2.6 - The main countries where the documents are published.

| Country | Documents published |
|---|---|
| United States | 43 |
| Australia | 16 |
| United Kingdom | 14 |
| China | 8 |
| Brasil | 6 |
| Germany | 6 |
| Italy | 6 |
| South Korea | |
| Canada | 5 |
| Colombia | 4 |
| New Zealand | 4 |
| Sweden | |
| Finland | 2 |
| France | 2 |
| Israel | 2 |
| Spain | 2 |
| Switzerland | 2 |
| Others (1 each one) | 24 |
| Total | **155** |

### 2.3.1.4 Distribution of the documents by countries' organizations' researchers

The number of published documents was higher than the number of studies (112) because one paper could be published in more than one country. There were 29 countries and 160 organizations, most of all universities, with published documents, which demonstrates the interest in the subject in each country and all over the world.

The contribution score of each country to the research subject is shown in Table 2.7 using the multiauthor paper score matrix shown in Table 2.8. The countries that contributed to the subject of the research during the period studied are identified in Table 2.5 and 2.6, the first with the author's affiliations, and in table 2.7 together with the number of institutions/universities, researchers, and papers. The USA, Australia, the UK, China, and Germany were the top five countries. In the US, 104 researchers from 61 organizations published 45 papers on the research subject, whereas in Australia, 50 scholars in 23 organizations contributed 15 publications during the period covered by the study. These results are reasonable because the US and Australia, for example, are internationally known as forerunners of the implementation of Stormwater Utilities (Chalfant, 2018). Australia has also made good progress in institutional sectoral arrangements, which could be credited to the fact that the country has established a well-organized sanitation sector (Marques, 2011). In Germany, 13 researchers from ten research centers published seven papers. Some developing countries, such as India and South Africa, despite having low scores (1.00 and 0.03), published papers showing growing interest in the subject. Table 2.4 above shows the twenty-four most active researchers with two or more papers, and the other 136 are all authors of just one paper.

Although contributing to most of the publications, nations such as the USA and Australia, have individual researchers with low scores because of the large number of researcher collaborations in particular publications. Identifying the contributions of countries, organizations, universities, and authors is important for researchers and practitioners for future collaborations.

Table 2.7 - Score distribution of countries, organizations, researchers, and papers.

| Country | O. | R. | P. | Score | Country | O. | R. | P. | Score |
|---|---|---|---|---|---|---|---|---|---|
| USA | 61 | 104 | 45 | 41.88 | Belgium | 1 | 3 | 1 | 1.00 |
| Australia | 23 | 50 | 15 | 12.87 | Poland | 1 | 2 | 1 | 1.00 |
| UK | 19 | 33 | 14 | 11.38 | Israel | 1 | 4 | 1 | 1.00 |
| China | 17 | 33 | 8 | 6.45 | Indonesia | 1 | 4 | 1 | 1.00 |
| Germany | 10 | 13 | 7 | 6.28 | Bangladesh | 3 | 3 | 1 | 1.00 |
| Canada | 10 | 15 | 6 | 5.22 | Tanzania | 1 | 1 | 1 | 1.00 |
| Italy | 9 | 20 | 5 | 5.00 | India | 1 | 2 | 1 | 1.00 |
| Brazil | 6 | 13 | 6 | 4.54 | Mexico | 1 | 2 | 1 | 0.46 |
| Colombia | 5 | 9 | 3 | 4.00 | Malaysia | 1 | 3 | 1 | 0.36 |
| N. Zealand | 2 | 11 | 4 | 3.64 | Greece | 1 | 1 | 1 | 0.32 |
| South Korea | 6 | 7 | 6 | 3.32 | Saudi Arabia | 1 | 1 | 1 | 0.18 |
| Spain | 5 | 6 | 2 | 2.00 | Sweden | 1 | 1 | 1 | 0.12 |
| France | 2 | 7 | 2 | 2.00 | S. Africa | 1 | 1 | 1 | 0.03 |
| Finland | 2 | 3 | 2 | 1.42 | Japan | 1 | 1 | 1 | 0.03 |
| Switzerland | 2 | 3 | 2 | 1.42 | | | | | |

Table 2.8 - Score matrix for multiauthor papers.

| Number of authors | Order of specific author | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 1.00 | | | | | |
| 2 | 0.60 | 0.40 | | | | |
| 3 | 0.47 | 0.32 | 0.21 | | | |
| 4 | 0.42 | 0.28 | 0.18 | 0.12 | | |
| 5 | 0.38 | 0.26 | 0.17 | 0.11 | 0.08 | |
| 6 | 0.37 | 0.24 | 0.16 | 0.11 | 0.07 | 0.05 |

To assess the contributions of countries and researchers to this research, an equation proposed by Howard et al. (1987) was used. This formula has been extensively used in previous review studies (Darko and Chan, 2016; Hong and Chan, 2014; Ke et al. 2009).

$$\text{Score} = (1.5)^{n-i} / \sum_{i}^{n} (1.5)^{n-i} \quad \text{(Equation 2.1)}$$

where n = number of authors and i = order of a specific author. Applying this formula, each paper was assigned a score of 1.00. Based on the position of authors on a multiauthor paper, the formula gives scores for authors. This formula assumes that a first author has made a greater contribution than a second author, a second author has contributed more than a third author, and so on, for example, if an author is the first author of Paper A, the second author of Paper B, and the third author of Paper C, assuming each paper which could also be used to score the author's country has three authors, the score of this author is 0.47 + 0.32 + 0.21 = 1. According to this methodology, each author's score was calculated, and after the duplicated authors were excluded, all were added to determine the contribution score of each country. We can conclude that both developed and developing countries are present, suggesting that this topic is of global interest.

### 2.3.2 Semantic Analysis

#### 2.3.2.1 Word cloud

Word cloud generators can be seen as exploratory tools and help find, in all titles, abstracts, and keywords, of the 112 documents, the word frequency of related terms enabling the differentiation of the high-frequency words, and the result is a visual word frequency cloud like in Figure 2.4 with the 50 most frequent words. The software (Word Cloud Generator by Monkey Learn) permits not just search by words (e.g., management, stormwater, regulations, and drainage) but related joint associated terms in expressions like "stormwater management" or "rainwater harvesting". Then, the software analyzes the words in two ways: a) according to the frequency of terms or b) according to the relevance of the terms and not just the frequency. For the first (a), the twelve most frequent terms cited and relevant are management (207 times, 0.515); policy (116 times, 0.245); regulations (97 times, 0.448); study (74 times, 0.267); results (64 times, 0.316); stormwater management (62 times, 0.665); paper (53 times, 0.453); harvesting (49 times, 0.460); rainwater harvesting (42 times, 0.808); drainage system (29 times, 0.333); green infrastructure (26 times, 0.665), and green space (16 times, 0.285). In the second approach (b), the twelve most relevant terms, times cited and relevance are urban water management (14 times, 0.998); rainwater harvesting (42 times, 0.808); urban drainage system (11 times, 0.784); urban green space (10 times, 0.713); stormwater management (62 times, 0.665); green infrastructure (26 times, 0.665); rainwater harvesting system (8 times, 0.570); management (207 times, 0.515); sustainable drainage system (7 times, 0.499); low impact development - LID (7 times, 0.499); best management practice (7 times, 0.499); harvesting (49 times, 0.460). The software analysis can consider not only the frequency but also the relevance of the terms. The software also presents a table with the “word”, “count” and “relevance” of all main words. In short, the terms “regulation”, “urban water management”, “rainwater harvesting”, “SUDS”, “urban drainage systems”, “stormwater management”, “green infrastructure”, “low impact development-LID”, and “urban green space” are popular topics.


Figure 2.4 - Research Word Cloud with the 50 most frequent terms.

#### 2.3.2.2 Conceptual Map

A data mining tool can be used to analyze the content of textual documents and visually display information by a conceptual map representing the main themes and concepts and how they are correlated. It is possible to visualize both quantifying the importance of the main concepts discussed in the document set and displaying the conceptual structure linking concepts. The tool used in this article – Leximancer – automatically extracts the most important concepts and builds a concept map. Three main sources of information about the document set are provided by the software: a) the main concepts and their relative importance; b) the strengths of links between concepts (how often they co-occur); and c) the similarities in the context in which they occur.

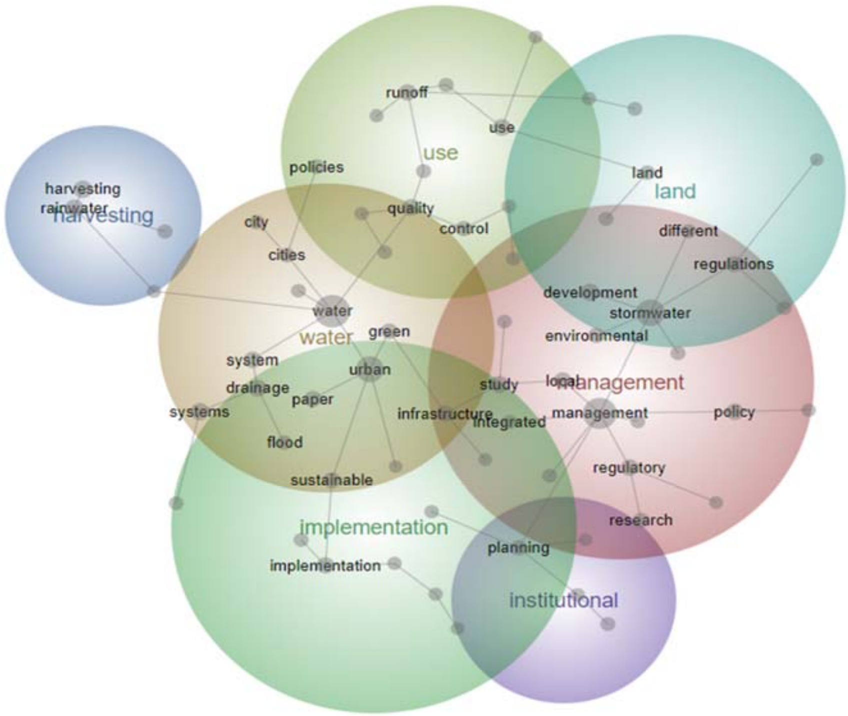


Figure 2.5 - Conceptual Map by Leximancer.

Leximancer's results, in Figure 2.5, revealed 7 themes, and the most cited interrelated themes were water, management, land, use, harvesting, implementation, and institutional. Leximancer concepts are defined as collections of words that occur together throughout the text. The thirteen main themes are water, management, stormwater, urban, harvesting, rainwater, systems, drainage, policy, use, development, implementation, and regulation. For example, the water theme shows correlation with the concepts of cities, quality, urban, system, green, flood, infrastructure, and sustainability, and the management theme is associated with the concepts of policy, regulatory, integrated, research, local, development, stormwater, infrastructure, and study. The implementation theme is related to sustainability, urban, drainage, flood, infrastructure, and planning and use correlates with runoff, quality, control, and policies.

### 2.3.3 Narrative analysis

Narrative analysis refers to the presentation and exposition, in more detail, the main themes pointed out in the 112 studies were obtained from the research carried out by the search engine Scopus.

The main issues and challenges in the urban drainage and stormwater sector are related to the lack of institutionalization, policies and regulation, and according to recent approaches, system performance depends on the alignment between the three elements of the PIR approach, which are mostly absent or misaligned in most municipalities and jurisdictions.

According to the survey results, six areas of greatest interest, all interconnected, are found: institutional arrangements, policy implementation, public regulation, governance, low impact development (LID), and rainwater. Although interconnected, they can be grouped into three themes: institutions and governance, policy implementation, and framework and regulation.

#### 2.3.3.1 Theme 1: Institutions and Governance

There is a great concern, reflected in many articles, related to institutions and governance of the water systems in terms of the sector organization such as in the articles referring to China (Chen et al., 2019), among other countries, in a context of hybrid coexistence between a "two-hand" system, i.e., on the one hand with power concentrated by the central government with investments in infrastructure and on the other hand with market principles and local governance powers. Another aspect highlighted in the Chinese context is economic development vs. water management and how to build a win–win strategy. In particular, here, the sponge cities concept is emphasized (Li et al. 2017).

In Germany, two key tools for regulating stormwater management are the compulsory connection and usage of stormwater charges. The question is how these two tools can link decentralization with the objectives of stormwater management and which institutional designs can integrate private owners into a strategy not only for new areas but also for existing settlements (Geyler et al., 2019).

Stormwater has increasingly become a resource and not a flood or pollution problem, but every innovation has risks and responsibilities in management. Urban water alternatives are considered and can have implications on how risk is conceptualized and managed, which involves how governance arrangements and risk allocation interact. Community perceptions are important, and different cities do not have the same perception of risk. In Chicago in the USA, there are many aspects of convergence and divergence about this and broader stakeholder participation in urban governance and decision making. Two dominant perspectives in terms of stormwater management interact and conflict: the infrastructural interventionist and the institutional interventionist. The first views laws and regulations and the second considers new rules and integrated management with more robust economic instruments as the best ways to improve drainage systems. (Cousins, 2017).

In Australia, policy changes are often recommended to promote the sustainability and resilience of the Murray-Darling Basin Authority (MDBA) practices to provide effective water regulation. A linear park project – River Torrens Linear Park (RTLP), a green infrastructure, in Australia – is an example of challenges in terms of institutional and political framework and governance because it involves many stakeholders and various political and institutional aspects, as presented in Figure 2.6 (Ibrahim et al., 2020).

The RTLP project is a good example of how the paradigm shift from traditional to sustainable drainage can mean an increase in complexity due to the entry of many actors, that is, the more functions there are for stormwater, the greater the number of actors competing for decisions about the fate of this resource, often with distinct interests. In the case of the RTLP, figure 2.6, in a simplified way, tries to demonstrate a large number of actors and aspects involved by showing explicitly the political, institutional and regulatory systems. Schematically it divides into internal and external factors, the latter being classified as PIR systems. The issue, in brief, means that the paradigm shift brings multiple objectives and multiple actors, requiring not only a change of vision and mentality but also a sharing of responsibilities, a fact witnessed in the RTLP project.


Figure 2.6 - Factors influencing the performance of the River Torrens Linear Park – a green infrastructure (Ibrahim et al. 2018).

The implementation of sustainable drainage systems (SUDS) have become a trend in the world, but in Poland, conventional systems continue to be the main methods of stormwater management, and the change depends on legal regulation barriers (Kordana, and Słyś, 2020).

Australia's SUDS approach integrates urban planning and design with urban water cycle management as the best management practices together with LID, popular in the USA and Europe, but finds barriers in the limited awareness of planners, engineers (Nunes et al. 2012) and others, as in the UK (Vilcan and Potter, 2020). In terms of SUDS options, in Italy, green roofs show better performance than porous pavements, highlighting the limits of run-off regulation with SUDS just in public areas and suggesting that it is important to build policies to provide incentives to private entities to adopt SUDS (Pappalardo et al., 2017).

In Canada, one of the most decentralized OECD countries, regarding governance, there is concern about the increasing complexity of basin management and water protection and how the relationship between decentralized and multilevel actors can hinder or help watershed management, especially the protection of water resources. In addition, the costs of stormwater management and maintenance are rising, and user pay implementation faces obstacles such as public perception and start-up costs (Cameron et al., 1999).

Governance in megacities is a complex task and involves many aspects, such as the gap in investment funds to construct and maintain the water infrastructure in addition to an inadequate institutional framework with deficiencies in legal and regulatory regimes (Varis et al., 2006). In the case of New York, the conditions under which the decision makers operate must be understood by considering local problems, such as fragmented jurisdiction and stormwater management under compliance with federal regulations, so that an adaptive governance approach is needed to manage this complex environment (Tryhorn, 2010). This greater institutional complexity with many actors and new policy trends, such as rainwater harvesting (Ghaffarianhoseini et al., 2016), has impacts on stormwater governance (Hopkins et al., 2018) with, for example, the institutionalization of rainwater harvesting through market-based tools (Fricano and Grass, 2014), demanding government regulation, and green infrastructure projects (Ibrahim et al., 2020).

#### 2.3.3.2 Theme 2: Policy implementation and framework

Theme 2 is related to policy implementation and the framework. For example, in Colombia, rainwater resource management has poor public policies integrating the urban design of cities (Villegas-Rodríguez et al., 2019) and also encounters barriers of inflexible policies and institutional fragmentation to make cities water sensitive (Torres et al., 2019).

Decades of implementing rainwater detention systems with little evaluation of their effectiveness demonstrate how necessary it is to collect data and information so that policies regarding these systems can be improved (Drumond et al.,2020).

The growing interest in green infrastructure policies and their potential to provide stormwater management in conjunction with other urban systems in many localities, such as Baltimore, represents a diverse portfolio including not only detention basins but also filters, infiltration facilities, and swales improving the water quality (McPhillips and Matsler, 2018). Despite being sustainable, green infrastructure implementation is slow, and gray infrastructure is usual in urban areas, showing differences between knowledge and practices with many barriers from cognitive to socio-institutional arrangements (Dhakal and Chevalier, 2017).

In Italy, a simulation study with different SUDS options showed better performance by green roofs than permeable pavements, suggesting that innovative policies may encourage more private landowners to adopt this kind of green infrastructure (Pappalardo et al., 2017).

For decades, decentralized management of stormwater, rainwater harvesting, and utilization in Germany have been supported by policies and regulations that function as incentives for utilization by public and private actors (Schuetze, 2013).

Policies of prohibition of rainwater and stormwater harvesting in Colorado and Utah frustrate the ability to control runoff and water pollution and are barriers for cities to deal with shortages of water resources, which is not sustainable (Cummings, 2012).

Urban rainwater harvesting policies can support a dual mode water supply system in Singapore (Chen et al., 2011), and in Indian megacities, a model involving rainwater harvesting and efficiency improvement concludes that these two policies combined can satisfy the criteria of efficiency, reliability, equity, financial viability, and revenue generation (Srinivasan et al., 2010a). In South Korea, rainwater harvesting is becoming more important, and governments have published a series of utilization policies and regulations (Lee et al.,2010).

As they are more cost-effective and compatible with the urban water cycle, several policies involving source pollution control techniques (e.g., retention, infiltration, reuse) have been implemented in Europe (the UK, France, Sweden, Denmark, Germany, the Netherlands, and Greece) for the management of urban stormwater (Chouli et al. 2007).

Pennsylvania stormwater management policy is consistent with other policies such as the Clean Streams Law and other federal and state regulations because it incorporates these related water policies and ensures that the involved parties have their demands met (Miltenberger, 2002).

#### 2.3.3.3 Theme 3: Regulation

There are two sides to the issue of regulation: the first addresses the regulation of the quality of service provision, basically linked to technological issues and the techniques and practices applied in the management of stormwater systems and closely linked to issues of pollution and flooding, and the second addresses economic regulation, linked to issues involving forms of financing and economic sustainability of actions and systems.

Most of the articles deal with quality regulation and a small number with economic regulation, often in a superficial way, with little questioning of the incentives for the actors to participate in the financing and investment and even less presentation of alternatives for its realization, but this may be due to the lack of institutional and political structuring of stormwater drainage and management in many cities, among other factors.

The lack of data on costs and system performance is a barrier to all kinds of initiatives in the urban drainage and stormwater management sector, including economic regulation; not only because it becomes an impediment to projects that can be financed, whether new or even retrofit projects that practically do not exist today, but also due to the lack of tools to enable the application of private resources (Dhakal and Chevalier, 2017).

Despite this reality, when the limits of regulation are reached or are insufficient, market-based tools can be attractive to encourage private owners to install green infrastructure (GI), as shown in Table 2.9. Thus, in the US, there are several pioneering initiatives in 400 cities that impose tariffs on impermeable areas, of which 70 cities in 20 states offer incentives through credits based on these tariffs for the installation of GI (Dhakal and Chevalier, 2017).

Table 2.9 - Potential market (or quasi market) mechanisms and examples (Dhakal and Chevalier, 2017).

| Policy mechanisms | Example applications |
|---|---|
| *Stormwater fee and discounts:* This scheme enforces a fee on runoff quantity or impervious area and provides discounts for installing GI. | Seattle enforces annual flat fee for single family and duplex smaller than 929 $m^2$. For all other cases, the annual fee is based on impervious area. Portland enforces off-site (65%) and on-site (35%) charges separately. Flat rate for single family to 4-plex residences, rate per 92.9 $m^2$ of impervious area in other cases. The Clean River Rewards program provides up to 100% of discounts for on-site portion of the charge. |
| *Allowance market:* In this scheme, tradable allowances of discharge are distributed among landowners, who are required to manage additional quantity. One who can manage more than required, can sell his allowances to others willing to buy and use them for their retention requirements. | Stormwater Retention Credit (SRC) program in Washington DC, US. Landowners obtain SRCs for voluntary reduction of stormwater runoff (one SRC per additional gallon reduced above required reduction) using GI. The owners can bank for future use or trade their SRCs in an open market to others who are willing to buy and use to meet regulatory requirements for retaining stormwater (Hoffmann et al., 2013). First of its kind in the nation. |
| *Payment for ecosystem services:* Owners are payed for providing ecosystem services such as flood mitigation, carbon storage, and water purification. | In use by US cities—such as New York, NY; Syracuse, NY; Boston, MA; Portland, OR; Seattle, WA—for protection of watershed that are their critical sources of water supply (Mercer et al., 2011). Used for many other ecosystem services, in countries including the US, China, South Africa, Mexico, Costa Rica, and Nicaragua (Schomers and Matzdorf, 2013). |
| *Rebates, credits, and installation financing:* This includes financing, tax credits, or reimbursements to landowners who install GI. | In Philadelphia, the Tree Vitalization Rebate Program provides a $25 rebate for planting a tree. The Rain Check program provides rain barrels for free and/or helps construct downspout planter, rain garden, or porous paving for a reduced price. In Seattle, the City and King County pays up to total cost of rain gardens and cisterns. |
| *Development incentives:* Developers receive benefits including expedited permitting, and bonuses for floor area, height, density, and space. | Chicago offers expedited permitting process for projects meeting Leadership in Energy and Environmental Design (LEED) criteria. For installing green roof, Philadelphia provides floor area ratio and height bonuses up to 400% and 10.97 m respectively; whereas Portland provides floor area bonus up to 300% of the area of ecoroof installed. |
| *Grants and awards:* Provides money directly to individual landowners or communities for installing GI. | In Chicago, the Green Roof Grant program provides $5000 to residential and small (<929 $m^2$) commercial buildings. In Portland, the Community Watershed Stewardship Program provides up to $10,000 for watershed restoration activities. Philadelphia has Stormwater Management Incentive Program (SMIP) to provide grants for qualified non-residential owners, and Green Acres Retrofit Program (GARP) to provide grants for qualified contractors, companies or projector aggregators. |

There are also initiatives such as that of the US Congress that proposed an addendum to the Clean Water Act (CWA) to charge the federal government for stormwater management fees where applicable (Norton, 2010) and proposals to finance social tariffs for those who cannot afford the fees.

In the USA, public health and environmental regulations make stormwater management an important issue and simultaneously a resource for water supply, especially in semiarid regions (Read et al., 2019).

The decentralization of stormwater management is a strategy that seeks to reduce the flows and optimization of existing systems and those to be built. In the first case, there is difficulty in implementing decentralization without the participation of existing owners, and thus, regulation should incorporate strategies of involvement and incentives for participation through the use of institutionalized instruments of compulsory connection and tariffs (Geyler et al., 2019).

In Israel, the transition from conventional to Sustainable Urban Drainage System (SUDS) management brought changes to the regulation system, particularly incorporating infiltration aspects and within the socio-institutional framework (Goulden et al., 2018).

Investments in green stormwater infrastructure are increasing in US cities and have the potential to carry out stormwater management along with other services, such as ecosystems dealing, for example, with problems of urban heat islands and urban environments and simultaneously bringing economic and regulatory changes (Hopkins et al., 2018), but its implementation remains slow (Dhakal and Chevalier, 2017; William et al., 2017).

In Bangkok, Thailand, the regulatory and institutional framework is weak and limited, with physical and financial barriers and little community involvement in the implementation of catchment basins approaches and source stormwater control. (Maneewan and Van Roon, 2017).

The scarcity of water in urban areas necessitates a consideration of the use of rainwater, but for this it is necessary to regulate and encourage its use, especially to face the risks involved (Ahmad and Ashfaq, 2011).

## 2.4 Discussion

The literature review carried out in this study, based on a survey of articles published over the last decades, since 1980, aimed at verifying what is present (or absent) in these documents to enabling an understanding of the subject of urban stormwater drainage and management beyond the technological challenges involving issues that relate it to PIR.

The intended contribution was to systematize the existing knowledge in the accessed literature and, through the use of electronic resources with machine learning, to present the themes and the existing relations between them that allow one to have an idea of what has been and what is being studied about urban stormwater drainage and management.

There are some good papers in the literature with interesting and comprehensive discussions and reflections, especially with regard to those themes more linked to the traditional view of drainage and less linked to the management of rainwater. However, part of the literature focuses on the items of the new paradigm, that is, rainwater as a resource and its management and control at the source, place of precipitation, when possible, and the search for a way to make its management economically viable through the use of regulation.

The instruments found in the literature that exist today and many of them in the USA are still in their infancy, needing to mature to have their potential fully utilized, but they are promising and are based on experience.

There is a significant increase in peer-reviewed papers referring to drainage systems policies, institutions and regulations - PIR subjects, especially in the last decade (2010) and at the beginning of 2020, with 84 (75%) produced articles, which allows us to assume that there is a growing interest in drainage PIR subjects. Most are published by authors from academic institutions in the USA, 45 (40%), and Australia, 15 (13%).

The evidence shows that there are no articles dealing specifically with the subject, and when there are, the effects of PIR on the results are just superficially approached. Despite this, the three correlated themes are present in the narrative analysis, i.e., institutions and governance - organizational, institutional and governance arrangements, policy implementation, structures, and regulation.

A good example of the interconnections between the sides of the PIR tripod is the example, briefly presented in figure 2.6, referring to the RTLP, in which the multiplicity of objectives entails a growing number of actors, often with diverging interests, making visible the presence of PIR, classified in this case as external factors, while the actors are acting internal factors.

The study's attributions derive from the use of what exists in a single database, albeit ample (SCOPUS), from the natural exclusions by the choice and analysis software used, and even relative to the period of time in which it was researched (from 1980 until 2020) with the prevailing trends in each time and place, that is, in the time and space of the research carried out.

In addition to the effects on results, it matters to recognize not just the gaps in politics, institutions and regulation, but the so called Good Enough Governance, or trying to focus not just on the gaps, but on the issues that give better results and in the “how” and “how many times” it will take to obtain results with the few available resources in each country and context.

## 2.5 Conclusions

This chapter contributes to the literature because it provides an analysis of the papers discussing PIR, related to the water drainage sector, so academia and practitioners can understand what exists and what are the gaps remaining on the subject and what is its importance for the paths toward the solutions required by the sector. The research process has obvious limitations due to the sample and existing papers in the database and by the choice of words used in the search engine.

This research is partially successful because despite having allowed us to identify that this subject is a reason for growing concern and reflection in all countries, showing its importance, it was not possible to identify a unique approach that allowed the comparison of effects and results of the PIR. This can be considered one of its major research challenges and limitations to the existing literature gap to be filled in future studies.

The lack of a single approach to such a complex subject should not surprise researchers, as the realities are quite diverse, which, however, does not prevent the search to identify not a particular reason or specific incentive for all places, but principles that can guide incentives to the alignment of PIR, at least in most situations, without this meaning a search for the unintelligent standardization of general criteria.

The work shows that future research must focus on identifying PIR priorities and especially incentives, among many existing demands, to define goals, such as SDG6, providing contributions to reduce poverty and increase people’s wellbeing. This is the challenge posed.

# 3. INSTITUTIONAL PARADIGM SHIFT: TRANSITIONS IN URBAN DRAINAGE

This chapter was submitted as article to an international peer-reviewed journal.

## 3.1 Introduction

Institutions are the rules of the game - formal (laws, decrees, and regulations) and informal (uses and customs) that must be followed by actors and organizations (North 1990). The policies (the goals of the game, can include strategies and actions) and the regulations (arbitration), that must be in accordance with the institutions, are situated within governance systems. Governance is a broad concept and a complex process of multilevel participation involving decision processes covering all groups of stakeholders interested and responsible for collective decisions where no part alone has power, information, knowledge or resources enough to unilaterally dominate the decision process (Kooiman & Jentoft 2009; Tortajada 2010). Thus, governance is founded on shared decisions while government is founded on formal authority decisions.

Governance differs from management in that while the latter is about goals and means, the former is about basic values, concepts, and principles. Thus, governance is built around the choice of values and principles which facilitates choices in hard decisions. Governance starts from determining what values and norms are at stake and identifies the fundamental principles. The principles express which values and norms are valid and determine which goals are ethical and reasonable. From there, choices can be made, decisions defined, and finally is that the means determined (Kooiman & Jentoff 2009).

Governance is considered one of the ways of governing, as are hierarchies, markets and networks, but in a broad view governance can be considered a hybrid model of all the others.

The local prevalence of the water services responsibility, according to the principle of subsidiarity, refers to aspects of the local institutional capacity of the municipalities, including the paradigm shift from traditional to sustainable management. The institutional capacity can be seen in three aspects: human, organizational, and management resources.

Changes in the concept and approach of stormwater management require compatible institutional and organizational structures (Dhakal & Chevalier 2016), overcoming issues of resolving only urban floods and rapid output of precipitations.

The absence of the subject in the political agendas not only reflects the obstacles to change with regard to concepts, but especially concerns the structures and actors responsible for change or, at least, the beginning of transformations. The question is how to institutionalize the changes and based on what factors.

The concept of evolution transformed the understanding in a way that conceptualizes rainwater not as a problem but as an available resource (Moissan 2013) able to contribute to the solution of many urban questions like the water scarcity, thermal comfort deficits, and many others (Vietz et al. 2018). Rainwater is the technical term for precipitation that falls on a property; once it leaves the property it becomes stormwater (Cutter & Pusch 2021). Stormwater is the portion of rainwater that flows over the land (Dhakal & Chevalier 2016).

The question to be faced is in what way the existing old and ageing infrastructures can adapt to the new society demands related, for example, to sustainability and climate and land use changes, adapting to available resources, and with motivation and organization of the social productive forces in each context.

The objective here is to provide an overview of existing structures problematizing the necessary changes in the face of the performance needs of the urban stormwater management sector and adding some case-studies where change is underway, to allow an understanding of how the changes can occur successfully overcoming the existing barriers.

The contribution is made through the analysis and discussion of existing governance and the necessary changes in existing institutional structures in stormwater management to face the challenges that are posed by adding a brief view of existing cases.

Following this introduction, section 2 discusses the governance concept in general and in the scope of stormwater management, and section 3 presents a description of the social and governmental agendas and institutional and organizational changes. Then, section 4 briefly displays, in a nutshell, the institutional changes necessary and provides examples of where institutional change has been underway to a greater or lesser extent. Section 5 discusses the case-studies and the major theoretical issues and finally, section 6 draws the main conclusions.

### 3.2 Governance and local capabilities

Governance deals with the management and transformation of structures and processes of the society or parts of it (Rijke et al. 2012). It can be defined and understood in different ways and, according to Rhodes (1996): "Governance refers to self-organizing, inter-organizational networks characterized by interdependence, resource-exchange, rules of the game, and significant autonomy from the state."

Governance, as structures, refers to the shape of the institutional design and to the mechanisms through which the social order is produced and reproduced (Voss 2007) and in this sense can be defined as: ''the patterns that emerge from governing activities of social, political and administrative actors'' (Kooiman 1993).

Governance, as a process, refers to networks, markets, hierarchies and communities (Rhodes 1996). In this sense, governance refers to govern and can be defined as "the setting, application, and enforcement of the rules of the game" (Kjaer 2004) or like ''all those activities of social, political and administrative that actors can be seen as purposeful efforts to guide, steer, control or manage (sectors or facets of) societies'' (Kooiman 1993). One of the aspects that distinguish governance and management is that in the last one the attention is focused on goals and means, while in the first, the governance, effort is made about reflection and deliberation of basic values, concepts, and principles, it is where any rational government process must start and end (Kooiman & Jentoft 2009).

The governance understanding to be considered here involves both concepts, governance as a process and as a structure: the networks of actors, institutional frameworks, and processes that take place within these networks and frameworks (Rijke et al. 2012).

Urban water governance refers to structures, processes, and mechanisms with multiple actors (state, private agents, and civil society) in urban water management (Dobbie et al. 2017).

Traditional, centralized governance, based on command and control, is not in line with the ongoing transformations that take decentralization and multi-stakeholder participation into account as key aspects, and thus governance with a different operational and strategic focus is required.

Implicitly or explicitly, governance practices involve making choices between standards, values, and principles, which is not always a simple matter, not only from the ethical and philosophical point of view, but due to value and normative conflicts (Kooiman & Jentoft 2009). The sustainable development question, for example, brings questions about the "development" and "sustainability" accepted degrees, when occurring together, compatible, or conflict. Some values and norms are related to specific cultures and situations like those who deal with man's relationships with nature, while the principles are more imperatives and concrete, derived from values and norms, more limited in scope, like the precaution principle, subordinated to the values of responsibility and care (Kooiman & Jentoft 2009).

Concerning the local governance, there is also an important ongoing paradigm shift, that is from the territory management and administrative boundaries, under the local administrations' responsibility, to the watershed hydrographic boundaries, more compatible with the integrated urban water management concept in the hydrological cycle. The question is more evident in metropolitan areas where there are several municipalities in the same basin, under not same rainwater events and neither always same problem, in function not only of their geographical characteristics (upstream and downstream), but also institutional, organizational, and resources issues, permeated by ideologically and conceptually different visions. The watershed water governance, overcomes not only the administrative borders but also the political boundaries, taking management beyond existing administrative and political structures and, therefore, the established hierarchical and power relations (Graefe 2011). The fact is that watershed governance can be understood as the depoliticization of management and the consensual arrangement between institutions (Swyngedouw 2009).

In terms of governance and planning based on the river basin scale, there are questions related to the best management scale, given transfers between basins with differences in the main objectives in each basin (Graefe 2011). The responsibility for management lies with the basin committees and objectives such as stormwater management, water scarcity, water supply, energy generation, and irrigation can be conflicting, making management more difficult.

The rainwater management by crossing municipal administrative boundaries, presents itself as a governance issue and requires institutions that share a unified view of the basin, upstream and downstream (Tucci & Meller 2007).

The existing traditional governance, in general, was adequate for the traditional management drainage systems based on a rapid water removal mentality. But this, besides modifying the hydrograms (graphical representation of flow versus time), incurs in undesirable effects on infiltration and the quality of receiving bodies. For some decades these effects have been mitigated by the adoption of the green technologies – Green Infrastructures (GI), that require a distributed management (Best Management Practices - BMPs, Water Sensitive Urban Design System - WSUD, Sustainable Urban Drainage System - SUDS and Low Impact Development - LID'S) involving multiple actors and a paradigm governance shift, from centralized ad technocratic, focused in command and control, to distributed and participatory (Dhakal & Chevalier 2016).

### 3.3 Urban social and environmental agendas – organizational and institutional changes

The social agendas brought by the international urban environmental movement since the 1990s, under the slogan of sustainable cities (Bibri & Krogstie 2017), are reflected in the Sustainable Development Goal 11 (SDG11) of the United Nations 2030 Agenda - Make cities and human settlements inclusive, safe, resilient and sustainable, and a goal entirely dedicated to the clean water and sanitation sectors (SDG6), that has the main objective of ensuring the availability and the sustainable management of Water and Sanitation for All.

In several parts of the world, there is evidence of a gradual paradigm shift from the traditional stormwater management, known as urban drainage, to the Sustainable Stormwater Management – SSWM as shown in Table 3.1.

Table 3.1 - Main aspects of urban drainage and Sustainable Stormwater Management - SSWM.

| ***Main aspects*** | ***Urban Drainage*** | ***Sustainable Stormwater Management - SSWM*** |
|---|---|---|
| Concept | Stormwater as a problem or a threat | Live with rainwater as a valued resource for humans and nature |
| Objectives | Avoid flooding, erosion, and sanitation risks | Deal with scarcity by harvesting rainwater, improving quality and flood mitigation, protecting water systems (river and lakes), increasing urban quality of life by urban nature and water systems, reducing urban heat islands and creating recreational and educational spaces, implementing low-cost infrastructures, make land more valuable and attractive to tourism (Ghofrani et al., 2017) |
| Actions | Rapid removal of runoff | Reduction of run-off flows and their peaks by detention, retention and infiltration and integration with traditional existing drainage structures |
| Professional roles | Engineers work after urban planning | Many kinds of professionals working together all the time: urban planners, engineers and nature specialists |

For some authors, like Tucci (Tucci 2012), among the main issues related to the urban stormwater is the allocation of space in cities. About the space destined for these waters, there is a new trend, within the concepts of sustainability, to no longer stay hidden underground, in tubes, galleries, and closed reservoirs, coming more and more to be present on the surface, enabling their coexistence with the population (Novaes & Netto 2019).

So, the structures of drainage systems, especially those participating in alternative systems, contrary to those who are conceived under the classic solutions, “tout a l’égout” or “drain rainwater as fast as possible”, take place in spaces intended for multiple uses, like many detention reservoirs, built in sports squares, draining gardens and porous pavements, all noticeably exposed to viewing by the inhabitants. This paradigm shift requires incentives from legislation (Arezes et al. 2019).

The biggest impediments to a paradigm shift from traditional stormwater management are not just purely technological but social and institutional (Brown & Farrelly 2009).

From an institutionalist approach and according to Ferguson et al. (2013), the transition between traditional systems and SSWM to address social choices shaped by the institutional environment can be accomplished through three pillars involving change: the cultural-cognitive, the normative, and the regulatory. The first pillar involves the willingness to change based on values, beliefs, and the knowledge of ways of doing, the second, involves moral and professional obligations contained, for example, in professional conduct and codes, and the last deals with legal obligations and regulatory coercions (Goulden et al. 2018). The nature of paradigm shift, therefore, involves changes in attitudes, norms, and regulation.

The governance inherited from the past, is based on a focused vision and mindset centered on technologies that consider urban waters in a fragmented way, thus the organizational structures currently found, still follow, in most cities, a separation between water supply, wastewater, groundwater, and stormwater with departments, rules, codes, and institutions in line with this thought.

Society tends to behave like that too, with the majority of public and private actors corroborating this understanding, i.e., that the centralized way, under the sole responsibility of the government, is the only solution to stormwater issues and not the sharing and co-responsibility of the whole society and its integration with other urban waters, from basin management and hydrological cycle perspective.

The internationally accepted concept of integration or Integrated Water Resources Management – IWRM, however, involves not only sectoral (horizontal) integration between water-related components (water supply, wastewater, stormwater, and groundwater) but multilevel (vertical) integration between different instances of power and decision-making (local, regional and national) institutional levels. In this way, the institutional structure of the state, centralized or decentralized, can influence decisions and the performance of stormwater management systems.

In a simplified way, states can be unitary states, such as China, or federal states, such as the U.S. where there is a constitution as a characteristic and the sharing of powers between the units of the federation, as well as their autonomy.

In federalized structures, although the degree of decentralization varies, according to the authority and responsibility of sub-national instances, the great challenge is to find a balance between the resources and responsibilities allocated to the national and sub-national levels. There are federal systems with a clear separation of powers, such as in the U.S., others that are more cooperative, such as in Germany and Switzerland, and others in which the national government controls resources and policies, such as in Venezuela (Muniz-Miranda & Reynard 2020).

The main difference between unitary states (even in those that are decentralized) and federal states is that in the former local authority can be questioned by national power at any time, while in democratic federations there are constitutional and institutional mechanisms to prevent an exaggerated concentration of power. Generally speaking, the greater the decentralization, the more complex the political system becomes due to the number of decision-making bodies and instances and local and regional policies, which may change over time, as is the case in Argentina, Brazil and Mexico (Muniz-Miranda and Reynard 2020).

Another aspect is related to the public participation in decision making, considered one of the institutional pillars of public policies, this participation does not always happen, which has been defined by some scholars like the phenomenon of "politics without public" that occurs when the interest of public groups in the subject does not happen, as was detected in Australia and that requires specific local mobilization strategies (Morison & Brown 2011) making these part of the transition from traditional management to WSUD.

The challenge is how to break outdated visions and the institutional path dependence, institutional inertia, and change the course to broad and participatory solutions, in accordance with current demands.

In this context, some questions deserve research and answers: How do institutions change and what social forces, actors and coalitions or events mobilize change? Where and when does the change process start and end and how do transaction costs behave? Can the management of rainwater happen as a public policy without public participation?

Real experience, arising from the implementation of various practices has much to contribute to the ideas coming from theoretical reflections, and in this way some examples are briefly presented in the following section.

## 3.4 Changing institutional structures

### 3.4.1 Australia

In Australia, the term Water Sensitive Urban Design – WSUD, started to be used in the 1990s (Fletcher et al. 2015), coined by Mouritz in 1992, with guidelines first published in 1994 and National Guidelines promulgated in 2009 (Radcliffe 2018). WSUD means “a philosophical approach to urban planning and design that aims to minimize the hydrological impact of urban development on the surrounding environment” (Lloyd et al. 2002) with four main objectives:

• Manage the water balance (considering ground-water and streamflow, along with flood damage and waterway erosion);

• Maintain and where possible enhance water quality (including sediment, protection of riparian vegetation, and minimizing the export of pollutants to surface and groundwater);

- Encourage water conservation, minimizing the import of potable water supply, through the harvesting of stormwater and the recycling of wastewater, and reductions in irrigation requirements;
- Maintain water-related environmental and recreational opportunities.

Australia, a country with a population of 24.7 million and a surface area of 7.7 million km², is highly urbanized, with 66% of the population living in Canberra, the nation's capital, and in five states capital cities (Brisbane, Sidney, Melbourne, Adelaide, and Perth). Situated on a continent with very low rainfall, does not use combined stormwater/sewage systems and, management of stormwater, largely managed by local government authorities, since the 1980s has undergone progressive changes and the creation of Environment Protection Authorities – EPA, had an important role.

A subset of WSUD, stormwater management is related to flood control, flow management, water quality improvements, and opportunities to harvest stormwater for non-potable uses, but there is also a need to consider stormwater management within an integrated framework for the entire urban water cycle, including rainwater, water supply, sewerage, and groundwater.

WSUD represents a significant shift in the way water and related environmental resources and water infrastructure are considered in the planning and design of cities and towns, at all scales and densities (Morison & Brown 2011). The WSUD approach considers the integration of all urban water streams within urban design. Works explicitly across all scales, and engages different types of professionals such as, planners, architects, social scientists, and ecologists. The term WSUD has also inspired a number of related concepts, such as climate sensitive urban design (Coutts et al. 2013) and a progressive move away from the principle of detention to the retention of stormwater (Allen et al. 2013) at the point where it falls, through the principle of "source control".

In Australia, WSUD, and water sensitive cities are two terms used, but there is an important distinction between the two: water sensitive city describes the objective, while WSUD describes the process.

WSUD is widely recognized across Australia, but the component priorities vary in response to local environments (Radcliffe 2018) and each State has specific instruments shown in table 3.2, and cumulative socio-political drivers.

The transition toward a Water Sensitive City (WSC) requires significant changes across the structures, cultures, and practices of urban and water system planning, design, management, engagement, and decision-making. A Cooperative Research Centre for Water Sensitive Cities (CRCWSC) developed the Transition Dynamics Framework which identifies six phases of change during a city's water sensitive transition: water supplied, sewered, drained, waterways, water cycle, and WSC. As a city moves through each phase, enabling conditions are established to support its trajectory towards WSC, avoiding the risks.

Table 3.2 - Australian States instruments.

| State – Capital | Instruments |
|---|---|
| Queensland – Brisbane | Healthy Land and Water program (2018)- Guidelines (2009) |
| New South Wales –Sidney | Building and Sustainability Index – BASIX (2000) |
| Victoria – Melbourne | Urban Stormwater –<br>Best Practice Environmental Management Guidelines (1999) |
| South Australia – Adelaide | South Australia Technical Manual (2010) |
| Western Australia – Perth | Department of Water and Environmental Regulation (2018) |
| Tasmania – Hobart | Tasmanian WSUD Procedures Manual (2012) |
| Capital Territory - Canberra | Territory Plan (ACT 2009) – Canberra WSUD Guidelines (2007) |
| Northern Territory - Darwin | NT (2009) WSUD Technical Design Guidelines |

A city's journey from a water supply city to WSC is not linear and Australian cities, like most cities in the world, are typically somewhere between a Drained City and a Water Cycle City, with observable features across all six of the city-states (Gunn et al. 2017).

### 3.4.2 The UK

In the UK, changes in the approach to stormwater management started in the 1980s. In 1992 guidelines were published and SuDS was first coined in 1997 by Jim Colin, of Scottish Water. Guidance documents were published in 2000 and the most authoritative guide currently used is the SuDS Manual by the Construction Industry Research and Information Association (CIRIA), a neutral, independent, not-for-profit body. The legislation specifying the use of SuDS in England is the Flood and Water Management Act, 2010 (Fletcher et al. 2015).

SuDS is based on the idea of replicating the natural, pre-development drainage from a site, using techniques to drain stormwater in a manner that mimics natural processes (infiltration, evapotranspiration, filtration, retention) and is more sustainable than the conventional way (Gimenez-Maranges et al. 2020), thus requiring a paradigm shift in the governance from centralized and technocratic to distributed and participatory (Dhakal & Chevalier 2016).

SuDS can take many forms, both above and below ground, some types including planting and other manufactured products, and besides that, is designed to manage and use rainwater close to where it falls, on the surface, incorporating vegetation, maximizing the opportunities and the four main categories of benefits that can be achieved by this systems: water quantity, water quality, amenity, and biodiversity, which are considered the four pillars of SuDS design as shown in figure 3.1 (Kellagher et al. 2015).

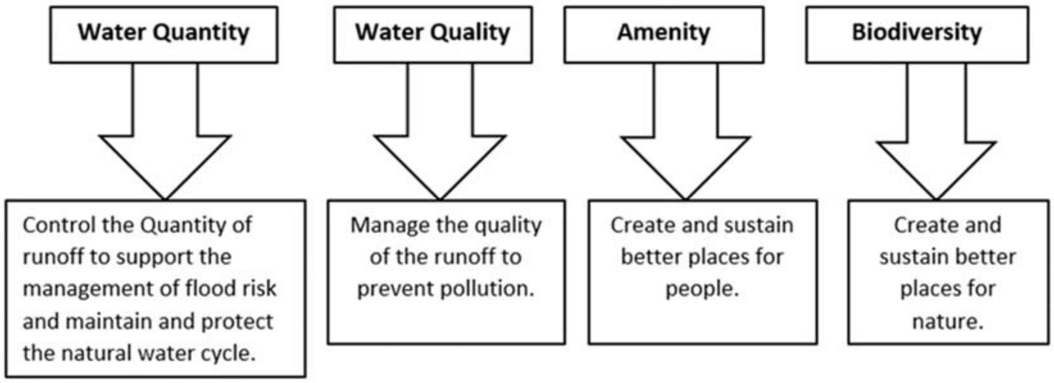


Figure 3.1 - Pillars of SuDS design (Kellagher et al. 2015, adapted).

Recent research demonstrates that in the last 19 years in 80 articles found there were very few articles which have focused on transitioning processes (11%) to a new paradigm – sustainable urban flood management. Social movements are not cited in the literature (Gimenez-Maranges et al. 2020).

In Europe, the UK is the only country where the three levels (local, regional and national) in a multi-scalar perspective of transition are present in literature and this might indicate major progress on SuDS. Despite this there is resistance and England (Newman et al. 2013) shows a slow pace transition to adoption of SuDS, but exists also some local-scale exceptions and in Scotland SuDS is “business-as-usual” (Ashley et al. 2015).

Until now, therefore, change remain technically focused with reduced transformation in mindset, knowledge, and governance.

Gimenez et al. (2020) pointed out that: “Despite the potential significance of the institutional change, shifts in practice are mostly perceived as simply the incorporating of a new technique (e.g. SuDS) within an already established institutional framework” and that “analysis of socio-tech transitions remains a research field in its infancy in Europe” with “change primarily taking place at neighborhood and single building level, while transition at larger scales remains challenging”.

The limited use of SuDS in the UK, as noted by Stovin (Stovin 2010) includes a mindset issue, a perceived risk associated with the lack of validated data on UK conditions, and modeling tools to assess the performance of a technology not widely used in addition to the lack of incentives for local authorities, developers and water utilities to implement any form of SuDS at a meaningful scale (Stovin 2010).

The most significant institutional change has been in the knowledge and mindset of professionals but the traditional culture is still dominant. SuDS are perceived as alternative solutions to current challenges thus this technique may be applied but the underlying thinking remains.

Cettner et. al. (2012) stated that besides society accepting pipe-bound centralized water and wastewater systems as “business-as-usual”, to obtain more sustainable systems, cities must break away physically and mentally from the traditional centralized solution system and its culture and recognize that the local solution (sustainable approach) and centralized (traditional approach) may also coexists together and that bridging the two approaches can be a better solution (Cettner et al. 2012).

### 3.4.3 The USA

The term Low Impact Development (LID) has been most used in North America since 1977 and the approach was “design with nature” trying to achieve a “natural” hydrology, attempting to minimize the cost of stormwater management, protecting areas such aquifer recharges and headwaters, discouraging the common practice of large end-of-catchment solutions and, by the end of 1990s, encompass any set of practices that treated stormwater (Fletcher et al. 2015).

In the US, Urban stormwater governance has a hierarchical structure including federal, state, and local governments as shown in table 3.3 (Bonneau et al. 2017).

Table 3.3 - US Governance structure (Bonneau et l. 2017 adapted).

| Level | Responsible structure | Activity |
|---|---|---|
| Federal | US Congress | Enacts laws (e.g., Clean Water Act) |
| | EPA | Enforces standards/regulations |
| States | States legislative and governments | Enact and implement more stringent standards |
| Local | City/County Governments | Implement federal and State laws |
| | | Enforce their own discretionary standards and regulations |
| Local | Designated agency (utility, department, bureau) | Governs all activities related to stormwater through its technocratic administration – *command and control* |

These existing stormwater governance structures are centralized and built to support conventional systems and not suited to the new distributed management approach, with multiple stakeholders (parcel owners, government agencies and non-governmental organizations), thus this incongruence, between technology and governance, calls for a paradigm shift from centralized and technocratic to distributed and participatory governance (Dhakal & Chevalier 2016).

Stormwater management was originally directed to the urban flooding problems from storms and the called gray infrastructure (system of pipes and gutters) made to collect and remove stormwater quickly out of urban sites but not addressing the environmental problems associated with hydrologic disruption.

Decentralized methods using vegetation and mimicking natural hydrology, under the name of GI, are a range of LID measures, like rain gardens, green roofs, rain barrels, permeable pavements, and vegetated swales and are cost effective when compared to gray infrastructure (Foster et al. 2011).

In a study with five US selected leader cities for GI implementation (Portland, Seattle, Philadelphia, Chicago, and Syracuse), the stormwater governance was evaluated using city codes and published materials considering gray and GI with a focus on the governance barriers to implementing GI (Dhakal & Chevalier 2016). It concluded that: 1) each city has a centralized agency governing through a command and control approach and technocratic and centralized governance; 2) the major functions that have major impacts on stormwater management (e.g., city planning, construction and maintenance in parks, zoning and development control) are not under the jurisdiction of the agency; 3) responsibilities are shared with other government agencies (e.g. county or state agencies); 4) incongruence between political and hydrological boundary with cities voluntary collaborating in shared regional watersheds, remaining lacks in decision making and enforcement authority; 5) cities encourage public participation but suggestions are not implemented; 6) there is no formal community level governance mechanisms to implement GI; 7) agencies have initiatives to their staff to implement GI and shift mindset of agency staff; 8) GI is predominantly limited to public land, but it is estimated that 65-75 percent of the land is private residential property; and finally the findings reveal that though the positive results, the governance problems remain as barriers, preventing the use of GI.

### 3.4.4 China

The trajectory of urban water management policies in China from 2000 (Qi et al. 2020) is shown in table 3.4.

Table 3.4 - Urban water management and Sponge Cities Program timeline in China (Qi et al. 2020 adapted).

| Timeline of Sponge Cities Program in China | | | | | | | |
|---|---|---|---|---|---|---|---|
| the 2000s | 2002 | )3 -2007 | 008 - 2010 | 2012 | 2013 | 2016 | 2018 |
| Focus on Water Supply projects | Water saving construction in pilot cities | Rainwater used in improved drainage systems, wastewater treatment | Allocation of water resources, considering water Management urban planning | Implement LID experiment at Shenzhen | SCP formally put forward by the Chinese government | The 30 pilot Cities Started to prepare for Urban Planning | The Ministry of Housing and Urban-Rural Development published the first draft of SCP assessment standards |
| Targets | 2015 - 2018 | Promote the SCP in the 30 pilot cities | | | | | |
| | 2018 – 2020 | Expand the SCP infrastructures to 20% of municipal areas by the end of 2020 | | | | | |
| | 2020 – 2030 | 80% of the municipal areas having SCP infrastructures towards the end of the 2030s | | | | | |

Since 2013, the Chinese government has taken the initiative to deal with frequent urban flooding through various policies and programs, among which the Sponge Cities Initiative (SCI) stands out as a holistic strategy for sustainable development that simultaneously cares for the environment and ecosystems, responding to flooding by taking into account the hydrological cycle. 30 out of 654 Chinese cities in two groups (16 cities in 2015 and 14 cities in 2016) including Beijing and Shanghai were chosen for the pilot experiment. According to the Task Force on Urban Flooding Problem and Solution Investigation (TFUFPSI), 641 Chinese cities are frequently exposed to flooding (Jiang et al. 2018).

At the same time, 45% of the cities have insufficient water supply and 17% of the cities have water shortages, with 30 out of 32 metropolitan areas with more than 1 million inhabitants having problems coping with water demand. In addition, urban areas are major points of degradation of water systems and disasters attributable to surface runoff. In addition to anthropogenic effects, urban sprawl has physical impacts on local weather patterns, such as variations in building height that create mechanical turbulence and barriers to the movement of precipitation, increasing its occurrence, as estimated through models that, between 2030 and 2040, indicate that Beijing should be prepared for more summer rainfall events (Zhan et al. 2013).

It is in this context that the concept of sponge cities was introduced to promote a paradigm shift in urban drainage and rainwater management. The idea of sponge cities is to preserve or restore the capacity of the land to store and absorb rainwater while being developed, reducing flood risks, reducing pollution from runoff, and increasing the water supply for different uses, including the environment. Engineers and urban planners must expand the vision from cities with too little water to cities with too much water (flooding) (Jiang & McBean 2021), towards its retention and sustainable use and integrated urban development within a holistic approach that involves urbanization, sustainable development, and addressing water and environmental challenges. In China the implementation of this initiative, SCI, is done in a top-down format, with socio-economic and land-use development planning by different administrative levels of government, responsible for the organization and coordination of the policy and its implementation.

Table 3.5 illustrates the functions and roles of the various instances and levels of government involved in the realization of sponge cities projects in China, involving not only the central government, but local governments, NGOs, and private sector actors (Qi et al. 2020). The role of evaluating and ensuring approval of the implementation of SCP projects is the responsibility of the National Development and Reform Commission, which is in charge of, among other activities, the new urbanization strategy, and plans, as well as designing policies and measures to encourage private sector investments.

From the point of view of the decision structure for the implementation of the initiative, some authors such as Wang et al. (2017) consider the centralized top-down format to be advantageous, although they recognize that for its success and sustainability to occur, several stakeholders must contribute, especially the participation of the population.

The Chinese government estimates that by 2020, in the pilot cities, 20% or more of urban areas will be included in the SCI, and by 2030, 80% of municipal areas will have sponge cities infrastructure projects, but recognizes that the cost of achieving this goal should not be borne by municipal governments alone. Thus, the Willingness to Pay (WTP) of the beneficiaries makes it possible to enable PPPs and, by providing incentives, for example by reducing fees to private developers, to increase the attractiveness of sponge cities' infrastructure in new projects (Qi et al. 2020).

Table 3.5 - SCP functions and roles of various instances and government levels in China.

| Actors | Departments | Responsibility | Main activities |
|---|---|---|---|
| Government Bureau | Ministry of Housing and Urban and Rural Development | Responsible for SCP construction projects in the 30 pilot cities and for operating and delivering SCP practices | Planning |
| | Minister of Water Resources | Land drainage system, offloading stormwater and urban surface water management responsibility, including all pluvial or inland floods. | Planning |
| | Minister of Finance | Financing and dealing with funds to support SCP development. | Financing |
| | Local Planning | Integration of SCP practice in the local development Plans process. | Planning |
| | Land Resources Bureau | Land use management coordination with the SCP projects and practices. | Planning |
| | Environmental Protection Bureau | Urban freshwater quality and environmental monitoring responsibility. | Planning |
| | Ministry of Forestry | Manage vegetation, green spaces, maintenance of flora in the SCP practice. | Planning |
| Communities | Non-Governmental Organizations (NGOs) and Community Groups | Present the public views and opinions of residents living by the SCP infrastructure (SCP Parks) to the governmental bureaus and enhance participation. | User Participation |
| Private sector | Developers | Develop surrounding areas that affiliate with SCP infrastructure and engage with municipal governments to enhance PPPs. | Private Participating |
| | Banks and Insurers | Provide financial support and insurance for the SCPs projects. | Financing |

Conceptually the initiative, based on absorption, storage, infiltration, purification, reuse, and when necessary, disposal of rainwater (Yin et al. 2021), is analogous to LID in the USA (Wang et al. 2017), SUDS in the U.K. and WSUD in Australia, but has greater scope by including conservation, recovery, and restoration of ecosystems that can serve as water reserves.

In addition to the availability of urban land for implementation and the low perception of the population, a factor usually considered as restrictive is the availability of resources, which are insufficient in many cities. Thus, the Chinese government has encouraged PPPs to boost the initiative without, however, having a specific model for the development of sponge cities (Wang et al. 2017).

## 3.5 Discussion

Water produces well-being in the city environment, but requires the integration between urban systems related to water (rainwater, stormwater, water supply, wastewater, and groundwater) and for this it depends on a complex management focused on the maintenance of the water urban cycle, which in turn, requires institutions structured to respond to the constant and permanent anthropic and natural challenges (Lloyd et al. 2002).

Thus, the forms practiced and the fragmented management structures (Vilcan & Potter 2020), as existing today, do not favor integration and disregard, for example, the use of rainwater as a resource (Radcliffe 2018), taking into account very small way issues of water quality and its impacts on the degradation of water resources.

The changes require the reconceptualization of urban waters and the practices and structures inherited from the past, with which the current situation cannot be modified or a change in the institutional inertia present in factors such as lack of organizational commitment and support resources, technology driven culture, professional expertise, legislation, power relations, technical-environmental discourse and tradition in pipe drainage (Cettner et al. 2014).

The centralized form, based on command and control (Tucci 2012), is in dissonance with the new decentralized, distributed, and participatory forms with multiple intervening actors that go beyond the municipal administrative boundaries when considering the river basins in the territory.

Another aspect interrelated with the changes concerns forms of financing of drainage structures and systems that do not have permanent sources of revenue (Veiga et al. 2021). Thus financing follows the old existing centralization while the new practices seek to merge centralization and decentralization in all aspects, including financing.

On the users' side, there are also needs for change so that from the understanding of the importance of urban rainwater and its management, they can also contribute with resources and participate in solutions and without them the policies can become “policies without publics” (Goulden et al. 2018) understanding the latter like groups interested in matters of public policy and not to specific corporate or other sector policy.

The municipal structures that hold the ownership of municipal actions are part of the problem, because they do not have the personnel, institutionalized sectors, and budget to deal with the subject (Heller 2012) and, therefore, are dependent on regional and federal structures for this, which does not always successfully happen, given the principle of subsidiarity and the degree of decentralization.

Governance is not only a structure, but also a process of multiple public and private actors (Rijke et al. 2012), involves choices, and these should be made involving the participation of all urban actors, in a basin perspective, that goes beyond purely administrative boundaries and considers the urban cycle of water, which today does not always happen and that, therefore, requires a paradigm shift. The changes have been taking place in several countries, but still slow in the face of the necessary and profound changes.

Finally, what can be seen from the examples presented is that they bring not only different physical implementation techniques, but also involve different aspects of system management and the organization of the structures for such, serving as a laboratory, as is the case in China (Li et al. 2016), for its large scale application, but also its unitary power system while many other federative and democratically participative systems present other faces to the same theme of urban stormwater management, and should have their performance data collected so that permanent evaluations can be made, making possible its improvement and adaptations from one place to another.

### 3.6 Conclusions

Understanding urban stormwater management requires a multidisciplinary approach which is natural for issues that involve great complexity, be it in terms of the number of actors or the aspects involving different and diverse socio-economic and environmental realities. Despite this, it is visibly clear that only technological changes are not capable of bringing the solutions that the issue requires, with social and institutional issues playing the main role.

The contributions herein are intended to provide reflection and understanding of the current context of a paradigm shift in urban stormwater management to assess situations where such change is more appropriate and should be accelerated and the difficulties and barriers that persist should and can be removed to evolve in urban well-being.

The process of transition from the conventional to the sustainable stormwater management paradigm requires a change in ideological thinking and systems of ideas according to the three pillars necessary for change: cognitive cultural (wanting change), normative (driven to change), and regulatory (having to change) and the concepts present in LID, SUDS, WSUD, and SCI, given their degree of institutionalization and the conditions existing today in the institutional context. It is not a simple task and we imagine that for it to be fully implemented will take, in terms of time horizon, a generation.

On the other hand, many of the advantages of these initiatives stem from efficiency gains produced from the combination of social, environmental, and economic benefits, including those related to combining investment agendas across various sectors, rather than from purely financial or single-sector benefits.

Thus, pilot projects should receive special attention regarding the production of information on these gains, which are often difficult to measure, so that their results can be evaluated and possible corrections and improvements can be made in new initiatives. Consider, for example, that the Chinese sponge cities projects were implemented recently and still do not have sufficient monitoring so that they can have their effectiveness evaluated.

Urban water management, particularly stormwater, is becoming increasingly complex and sophisticated, demanding an ambitious agenda whose limits lie not only in the field of financial resources but also in the existing governance and institutional gaps that condition the performance of the organizations involved.

Besides the natural restrictions on access to available information, the limitations of this study, however, lie in the rapid dynamics of the changes that are underway, taking place in various parts of the globe and the ability to be absorbed depending on events that may or may not accelerate them, as is the case of climate change that has a certain degree of unpredictability.

# 4. PUBLIC POLICY: URBAN STORMWATER IN A PARADIGM SHIFT, IS IT THE END OR JUST THE BEGINNING?

This chapter was published in the Water Science and Technology Journal, vol. 85, n.9, 2652-2662 doi: 10.2166/wst.2022.127

## 4.1 Introduction

Decisions made by governments are materialized through public policies that direct actions to achieve certain pre-defined objectives. Policies can be created and implemented through different instruments such as laws and regulations, specific actions, or even funding priorities. Policies can be responsible for leveraging incentives for sustainable service delivery and for enhancing and transforming the existing institutional and regulatory framework (Mumssen et al. 2018).

There are many interpretations of the word policy and one of them is a definition, according to Hill's review of the term (Hill & Varone 2021), present in the Oxford English Dictionary at 2nd ed. of 1989: 'A course of action adopted and pursued by a government, party, ruler statesman, etc.' In this sense, for example, Water Sensitive Urban Design (WSUD), is a water policy adopted and purposed by governments and professional institutions in Australia.

Public policies have two fundamental aspects: their formulation and their evaluation after application, which is the third and intermediate aspect, between the other two. The implementation stage has as determinants the organizational and political conditions, that is, political and the associated social costs within a governance structure and economic policy of the sector where, for example, some actions may have difficulties of political and public support for their implementation, despite being efficient (Mumssen et al. 2018). Several factors can inhibit policy implementation such as lack of qualified personnel, lack of leadership, opposition, corruption, and many others.

This chapter aims to present an overview of urban stormwater management policies as they relate to institutions and regulation, but with a special focus on the paradigm shift underway (Dhakal & Chevalier 2016) in several aspects that the complexity of the subject requires. Urban stormwater management is a complex issue, i.e., it involves multiple actors, is interdisciplinary, does not allow for accurate predictions as to its future course, and has consequences that feedback on its causes.

The ongoing paradigm shift takes place in most of the aspects involved such as: technological, environmental, economic, social, political, legal, and institutional (Furigo 2020). In technological terms, the perception that quantitative control, or control of volumes associated with precipitation, can be better carried out at the source and not at the end of the runoff makes it possible to resort to smaller and more cost-effective solutions, not excluding the simultaneous "end of the pipe" treatment, but which has a different conception.

As for the issue of runoff quality, or in terms of contamination, previously considered practically non-existent, which concerns the environmental aspect, imbricated with the technical solutions, there are treatment alternatives (Chouli 2006) also at the source or along with the runoff, but before the outlet, through techniques called alternatives, favoring the infiltration and evapotranspiration, as in detention basins, retention, bio-drainage ponds, porous pavements, and other alternatives. In the economic aspect, the present reflection is on the alternatives for obtaining resources and financing for the construction, operation, and maintenance of infrastructure systems.

Questions about the best way to obtain resources, whether from users (Zhao et al. 2019), taxpayers, or through creative solutions such as public-private partnerships arrangements (PPPs) or other forms that are legally and politically acceptable to society, and the absence of specific sources of funding for the activity, as is the case in most countries nowadays, transforms its funding into an aspect of change (Veiga et al. 2021), the same occurring with the institutional, organizational and management structures, including the structure of personnel and their training for the activity. In a simultaneous movement with the actors involved and their diverse interests, all these aspects require organizational and institutional structures subject to distributed governance, that is, with the democratic participation of the actors aimed at reaching consensual solutions.

Various aspects are being questioned such as the costs of alternative solutions in the face of budget restrictions, which on the one hand present barriers to their construction, but on the other hand present opportunities for change towards other ways of obtaining resources and financing systems and management structures with the participation of other stakeholders, including users or investors or those who for any reason have an interest in participating in projects and actions related to urban stormwater.

The methodology used is based on a narrative constructed from the bibliography available through research in databases such as Scopus, but also in various other means available, in networks and other sources of documents. The text was based on research, experience, and reflection and took into consideration the existing recent papers available in the literature accessed relying, therefore, on the international experience built over the last decades.

The main contribution of this research lies in the effort to systematize relevant issues around the subject of urban stormwater from a public policy perspective, which in practice are almost totally absent in most countries, regardless of their stage of development and their technical, socio-economic, and cultural context. For several reasons, this absence, materialized by the limited capacity to respond to rainfall events across the globe (Kondratenko et al. 2021), has caused concern among scholars and the public, to whom we hope to provide useful contributions.

The results obtained with existing policies or their absence are reflected in the fragile conditions presented by cities about rainfall events that invariably, whether in developed or developing countries, result in disruption and material and human losses. There are no ready formulas for dealing with stormwater runoff, but in each place, the structures in charge of these tasks deserve to be built, where they do not exist, or rethought in the light of new demands arising from the confluence of old and new events such as accelerated urbanization and climate change. All these elements have required changes in the way urban stormwater is treated, which we call a paradigm shift (Bertrand-Krajewski 2021). This change has already been occurring to varying degrees depending on the specific economic and social characteristics of each location with varying results, but with little impact on the specialist literature, reflecting the incipient discussion of this issue in academia or the lack of transparency of the discussions.

This chapter is structured in four sections in addition to this brief introduction. Section 2 deals with public policies including the Sustainable Development Goals (SDGs). Section 3 addresses the drainage policies emphasizing its financing. Section 4 discusses the results obtained and, finally, section 5 presents the concluding remarks.

## 4.2 Public Policies

### 4.2.1 *Background*

Public policies are always choices in a framework of preference conflicts, mediated by inclusive political institutions to a greater or lesser degree, which reflect the degree of influence of different actors in the decision-making process (Sarti et al. 2018).

Thus, public policies, as a result of political decisions, established in political processes characterized by the existence of different, and often conflicting conceptions (in terms of values and ideas) about the role of the state and its degree of intervention in society, are built not always from real problems, but from the understanding by political actors, both governmental and non-governmental, of what are problems or problematic situations that deserve to be part of a government agenda through a particular public policy.

Water and sanitation whose main function is the prevention and promotion of health refer to public policies related to health (Sarti et al. 2018), which is different from the classic policies of service provision as market goods. Since water and sanitation are not separated from health policies, intersectionality between these policies is necessary. However, this is not always the reality observed, which leads to a limited approach to health policies.

Changes in certain policies depend, however, on conjunctures, invariably provided by crises in which there are institutional imbalances favorable to change or opportunities for political transformations such as changes in government, economic changes, and others.

Additionally, from the perspective of the new institutionalism approach, in which institutions play a decisive role in policy outcomes, the alternatives of available policy choices are conditioned by the institutional effects of previous choices, that is, conditioned by past policies that established different actors and institutionalized certain practices and rules, configuring a relation of path dependence with the State as the structuring agent.

Public policies are also important rules of the game and, therefore, can be included in the list of institutions, and lead to the constitution of organizations and other institutions to enable their implementation.

In societies under democratic regimes, in which power alternates, water and sanitation public policies, including long-term planning, are State policies and not just government policies, since the latter is transitory.

### 4.2.2 Sustainable Development Goals – SDG's Policies

Water and sanitation as a right, recognized by the United Nations (UN) General Assembly (Resolution 64/292) and the Human Rights Council (Resolution 15/9) in 2010, refers to universal access to the related services and, therefore, the need for policies that consider, where the issue of access to all in an equitable way was not achieved yet. Universalization encompasses the inclusion of all water and sanitation services, non-intermittent and quality water supply, and comprehensive, including, when possible, fair tariffs established in a way that does not constitute an obstacle to universal provision (Neto & Camkin 2020).

In 2015, all UN Member States adopted the 2030 Agenda for Sustainable Development, including a goal (SDG6), with the main objective of ensuring the availability and the sustainable management of water and sanitation for all, but unless current rates of progress increase substantially, targets will not be met by 2030.

Thus, in 2020, according to the UN, even though handwashing is one of the cheapest, easiest, and most effective ways to prevent the spread of diseases, and also coronavirus, an estimated 3 billion people worldwide, could not wash their hands at home. However, nothing is said about rainwater, which is absent from the statistics and therefore from the analysis, even though it can be considered an important resource in solving the urban scarcity and other questions.

The level of water stress (SDG6.4.2 target), characterized by greater consumption of water from natural sources, is a phenomenon that occurs in most regions of the world. Urban consumption, besides trying to be more efficient, can have policies which improve the control of losses in the networks, use rainwater for non-potable uses, and also reuse the water used.

A recent World Bank study estimates that meeting the sixth of the SDGs could cost USD116 billion per year through 2030. These costs unbundle into the separate costs of providing safe water (USD37.6 billion per year), safe sanitation (USD19.5 billion per year), safe fecal waste management (USD49 billion per year), and hygiene facilities and education (USD2 billion per year) (Staddon et al. 2020). These costs are, however, minor compared to the costs necessary to get the economy going again in the post-pandemic period and may be smaller if rainwater is considered a resource.

Regarding SDG 11.3.1 and urban planning, given the expected increase in rainfall, studies in Hamilton, near Toronto, Canada, have found that population growth is higher than the increase in land use, which is a good indicator for urban stormwater management (Philip 2021).

### 4.2.3 Policies for the universalization of services

The biggest challenges to the universal access to water and sanitation services are the rural areas and the peripheral areas of the cities, including the big cities, such as São Paulo in Brazil where the issue of water security is very sensitive to several conditions such as social inequalities, environmental and climatic conditions, political processes and past events.

São Paulo, compared to London, in the UK, despite their differences and similarities, brought to light, during the event of the COVID-19 pandemic, the risks to which both populations are permanently subjected, especially the poorest and most vulnerable, and the importance of policies focusing on water security. There are several vulnerabilities, such as insufficient water reservoirs, inequalities in access to and use of water, overcrowded housing, and lack of shelter for many (Alves et al. 2021).

During the pandemic of COVID-19, at the same time as water scarcity for handwashing occurred, flooding events occurred in 70 countries (Simonovic 2021). While the pandemic requires isolation and social distancing, flooding events require or entail, on many occasions, proximity between people, making the goals contradictory for given moments. This reality makes it necessary to think about policies that consider the possible occurrence of multiple simultaneous adverse events (e.g., pandemic and water scarcity or excess). This can be taken into account through scenario simulations considering the concept of dynamic resilience, i.e., in which actions may be modified according to the evolution of events. This possibility is unusual among decision-makers who need to adapt to the concept of dynamic resilience by receiving information in advance so that they can formulate policies and plan actions, i.e., that include the greatest possible resilience of existing systems, which requires a change in thinking from static to dynamic resilience and from one adverse event to multiple simultaneous adverse events.

The implementation of policies aimed at the use of rainwater, within the logic of the urban water cycle, in the same way, that the conscious use of groundwater which can even count on receiving contributions from rainwater, deserves to be encouraged, not only for the potential of facing the urban water shortage and, therefore, not only to meet the proposed in SDG6, but also to combat situations of vulnerability to diseases, especially those related to floods.

Urban rainwater certainly has an important role to play in combating situations of scarcity or excess in cities, but to do so it needs to have adequate management policies that are integrated with health, housing, and territorial and infrastructural planning policies.

## 4.3 Drainage Policies

### 4.3.1 Drainage policies in a nutshell

Drainage policies, except for the US, whose existence dates back to 1987 with the Clean Water Act (CWA), and Australia, where the Australian Drinking Water Guidelines exist since 1996 (Fletcher et al. 2015), do not have a long history. In Europe, drainage has recently received more attention, however, in other countries, such as Brazil, it is almost imperceptible (Montenegro, 2017). In China, with the recent greater development of cities, since 2015 there is a growing concern and the establishment of a national policy under the title of Sponge Cities (Yin et al. 2021).

Another aspect that influences the structuring of policies in the sector concerns the more general political structures, federalist, democratic, and distributed, as in the USA, or like China, with centralized political power. The legislation also follows this logic, with each country, state, municipality, district, county, or consortium and other forms of a grouping of federative entities having specific rules and ways to obtain different resources. It is important to note that stormwater does not follow the logic of administrative divisions and subdivisions, but rather that of hydrographic basins or hydrographic regions, containing several basins, as is the case in Portugal (Arezes 2019).

The logic of analysis by watersheds, however, is not exhausted in itself and leads us to think about natural and built territories, and thus, about the planning of their use and occupation, that is, about territorial planning as a basis. The territory is the space where planned actions take place as a result of negotiations and political interactions between the various actors present or with interests that occur in the territory. Through collective decisions, the municipalities seek to ensure quantity with quality, prevent floods and mitigate droughts, without pushing problems from one municipality to another.

Urban water management is subject to the interaction of numerous public interest groups, private or otherwise, which have contradictory and conflicting behaviors, but without them, it is difficult to obtain solutions that derive from shared decisions whose main objectives are flood and pollution control. Each optimal solution chosen represents the best possible compromise between the various interests at a given moment.

In this perspective of participation, it is in the territories, spaces where the actions take place, that the urbanistic projects, new or of urban requalification, respond to the interests of certain social groups and illustrate the political priorities (water saving, economic growth, health security, better standard of living, and environmental quality) that determine the decisions and choices made and to be made. This has been the case since the nineteenth century, a time when water and sanitation infrastructure was seen as a sign of modernity and urban comfort. However, since then, such technical superiority has foundations and arguments of socio-political order having been, for example, the Parisian option for what became known as "tout-à-l'égout", a strategic political decision in which the State assumed responsibility for the water evacuation and treatment, because Paris, being an important capital, could not have its image damaged by the ways of handling water and sanitation as the transportation of sewage through the streets (Chouli 2006).

Urban hydrology, which had hygiene as its philosophical and theoretical foundation, is today a hybrid science involving physical phenomena, technical problems, urban society, and public policies and as such is in permanent evolution, not only in its technical and innovative aspects but because it has to consider socio-economic and environmental conditions.

Decisions within a preference system are made as a result of negotiations and depend on the players and information. Thus, the decision process itself may influence the decision made, such as, for instance, depending on the players who may propose, through an environmental institution, that environmental impact studies be considered or, for instance, if the technicians only present solutions based on channeling, other alternatives are discarded even though they are based on better accepted public policies, such as those that aim at water-saving, controlling urban rainwater runoff at the source and avoid the significant use of channeling.

The instruments used by actors to implement a public policy are represented by all activities, decisions, and measures aimed at solving a certain problem (laws, working methods, information campaigns, assignments of roles and powers, decisions to include different actors, or the choice of a management model). These instruments are characterized by their objectives and for urban stormwater management they can be classified into three types: command and control (legislation and regulation); fiscal incentive policies (runoff charges based on impermeable m²) and technical expertise, information, and public awareness, but one type of instrument may achieve several objectives at the same time (Chouli 2006).

Stormwater management in Europe can be described as a combination of four variables: direct or delegated management, management at the national, regional, or local level, management by the public or private sector, and management with or without partnerships, for example, direct management by the municipality or by a private company delegated by the central state or managed through a public partnership between local authorities and many other forms.

Alternative techniques, under the principle of decentralization and control of stormwater pollution at source, require new decision-making processes based on multidisciplinary collaboration, consensus between different actors, and different institutional, organizational structures, political (legal, economic, and socio-political) enforcement instruments. It is the legislation that creates the obligations to establish means including the installation of treatment plants or results such as the reduction of the concentrations of specific pollutants in the receiving bodies.

The European directives, e.g., Water Framework Directive (WFD) 2000/60/EC and the Directive 2007/60/CE, also known as the Floods Directive (FD), which has as their main objective the establishment of a general framework for the assessment and management of flood risks, do not focus on stormwater.

Initially, the WFD focused on the mitigation of pollution sources, such as agriculture, industry, effluent treatment plants, overflows from combined systems, and direct sewage discharges into receiving water bodies. Without paying attention to separate systems, especially stormwater discharges, disregarding its quality, considered until then not as a major problem, neither the WFD nor the FD use the term 'stormwater'. WFD only mentions the word "drainage" in the classification of surface waters as artificial or strongly impacted and when dealing with the contamination of groundwater by artificial recharge anthropogenically altered by rainwater runoff drainage. And finally, the word "precipitation" is used in the WFD only to describe the characteristics of rivers and FD never uses these words (Jensen et al. 2020).

Thus, an important policy change would be not only to adopt the terms but to consider the effects of the separate systems so that in Europe all impacts on the receiving bodies would be considered, aiming at total pollution control, which does not occur by leaving aside the stormwater separate system.

In Europe, concerning technology and investment priorities, and water management in cities, the first priority is related to the storage of water supply. The second is wastewater treatment, especially for sanitary reasons and to maintain the quality of receiving water bodies (lakes and rivers), often also used as a source of water resources, as is the case of rivers in France, Germany, the United Kingdom, and the Netherlands. Finally, the third priority refers to diffuse pollution that originates from two main sources: urban runoff and agriculture, the latter due to the use of pesticides and fertilizers.

In Portugal, there are references to stormwater in the Regulatory Decree No. 23/95, but stormwater drainage lacks specific regulation. However, the General Drainage Plan of Lisbon - PGDL 2016-2030, is a municipal strategic document that has as its political objective the preparation of the city for the future, mitigating the consequences of climate change expressed by significant and increasingly frequent rainfall events. One of the principles of this plan is the flow control at the source through the construction of retention and infiltration basins and drainage trenches, in addition to tunnels, pavements, and other interventions, amounting to a total value of 250M€ (Béraud et al. 2021).

Urban runoff, however, presents different problems when there are combined or separate systems, the former being more important in controlling overflows in rainy periods. This latter problem can be solved by the construction of separate systems and disconnection of stormwater from the combined system or by expanding sewers and treatment plants. In the case of separate systems, polluted effluent is also received in stormwater networks, especially in rainy periods due to the first flush, but also in dry periods due to illegal or poorly constructed wastewater connections and infiltration. Each situation presented requires specific policies for its solution. Additionally, a priority that runs parallel to the other three is flood protection.

### 4.3.2 Funding and financing policies

In Europe, the importance of urban stormwater management and, therefore, stormwater policies, increases over time, correlates with other technical priorities related to water quality, and can also be understood as the sum of the importance of flood protection and urban water quality. Such priorities, in each municipality, are influenced by local contexts and by national and regional policies, as well as by European Union policies.

Public policy funding actions refer to the real or perceived needs of coalitions of actors, especially those in power, and thus the funding of drainage systems requires them to be perceived as important by actors, especially decision-makers and society in general.

Water policies in cities have always focused mainly on water supply and wastewater, leaving rainwater in the background and, consequently, also the issues and policies related to it. From the end of the last century onwards and more recently, with the sense that issues of urban pollution, water scarcity, heat islands, and flooding, partly due to climate change, impact well-being and have undesirable costs on lives and property, rainwater has been better understood, in particular from the perspective of being considered as a resource rather than being seen as a problem, following the logic of the urban water cycle (Goulden et al. 2018).

As a result, the urban infrastructure responsible for stormwater management has received more attention in terms of the necessary resources to keep it running, but so far it has not received sufficient funds and financing to cope with the increasing demands that are being made on it.

There is no single solution for the funding issue, and in each place, the funding policy reflects the particular context, but as the necessary amounts are quite significant, it has been necessary to count on government funds at all levels (federal, regional, and local) through general or specific budgets, plus contributions from users and the private sector, or even donations.

As an example, in the USA, a country of large dimension, also due to the variety of configurations and legislation, there are several ways of financing and organizing the provision of services, among which the well-known stormwater entities, existing 1600, of the 7550 allowed, with dedicated sources of funds, such as fees and rates (EFAB & USEPA 2020).

In that country, where the annual operation, maintenance, and capital estimated funding gap for drainage systems is approximately USD 7-10 billion (EFAB & USEPA 2020), as in many others, there are policy barriers to obtaining funds and financing that range from the popular perception of the importance of the systems to the existence of legislation that in some places requires popular consultations with minimum quorums of participants.

The EPA identified stormwater runoff as the single fastest-growing source of pollution in the country and, starting in the 1990s, began to regulate the issue through a policy that relied on the permit program through the Federal Water Pollution Control Act, better known as the already mention CWA. In this context, in the USA, since then, 7855 discharge permits have been issued, according to the National Pollutant Discharge Elimination System (NPDES), which means a reach of 80% of the population.

The existence of systems with different characteristics, sometimes separate and other times combined, despite making matters more complex both in terms of those responsible for operation and maintenance and those who must provide the financial resources, does not prevent estimates of the financial needs. In a research conducted in 2012 and published in 2016, the EPA estimated a need for 67.2 billion dollars over the next 20 years in investments in both separate and combined systems. These amounts are equivalent to those spent in the past to initiate the construction of the interstate highway system or to upgrade wastewater treatment plants (EFAB & USEPA 2020).

In Brazil, between 2014 and 2033 the financing capital required according to the National Plan of Basic Sanitation – PLANSAB, in its version of 2013, is estimated at USD $33.6 billion over the twenty-year period or USD $ 1.7 billion/year (Montenegro 2017).

The need for funds and financing mechanisms for this infrastructure is always raising due to regulatory requirements, water quality degradation, flood risks, climate change, and aging infrastructure itself, and the costs of doing nothing outweigh these costs. Thus, all alternatives deserve to be considered: general public budgets, fees, tariffs, grants, loans, revenue bonds, partnerships, PPPs, volunteer programs, and other innovative approaches (e.g., sponsorship of stormwater infrastructure).

Part of the necessary resources for stormwater management systems can be obtained from each owner of the impermeable areas, according to the type of use (commercial, residential and industrial) in proportion to what they contribute to the runoff plus what would occur if there was no impermeability, according to the user-pays principle. The computation of these impermeable areas, however, is still not a simple task for a large part of the municipalities, which do not even have the staff and expertise for this, which requires measurements with the use of information technology and satellite images. The forms of cost attribution encounter technical and legal difficulties, and even in the USA, there is a lot of questioning, mostly demanded by non-residential owners, regarding both the legality of ownership for the imposition of fees and rates and the calculation of the parcels themselves. One aspect of interest is the proportion between areas of public responsibility, such as roads, squares, public buildings, and private areas. About this, in some locations in the USA, measurements identified between 65-75% of private areas able to receive green infrastructures (Dhakal & Chevalier 2016) and in Brazil, specifically in the Federal District, the split was approximately 50% between public and private.

Incentives through exemptions can also act as an incentive for private landowners to construct rainwater storage or utilization devices on their plots (e.g., green roofs) or to disconnect from public stormwater systems, leading to savings. Another form of incentive is paid to municipalities for the discharge of treated water of specified quality levels into receiving waters, as is already the case in Brazil, but only for wastewater effluent, which could be extended to stormwater. Brazil adopts a similar mechanism for effluents discharged into rivers, by the ANA-PRODES program, that seeks to encourage greater treatment of effluents.

All these issues show that stormwater solutions are typical of complex systems that require the participation of all actors, involve multidisciplinary, and have a great capacity to measure various items so that they can be fairly and equitably distributed.

The issue is not only the quantification of runoffs, which can be considered through the calculation of impermeable areas but also the quality aspects that, although they can be indirectly estimated through the classification of predominant uses, also bring complexity to the evaluation, for instance, of the types of existing pollutants, requiring, in each specific case, control and treatment alternatives with different costs, which leads to the valuation of the charge according to the polluter-pays principle.

Financing policies involve items related to environmental, social, economic, organizational, institutional, and political issues, they demand the kind of robustness only found with the participation of all actors and multidisciplinary foundation so that they obtain relevant results and leverage society's values.

### 4.4 Discussion

To achieve positive results in terms of human and environmental demands, policies addressing urban stormwater management require the challenging confrontation of a broad and deep paradigm shift, i.e., a change in the status quo of the provision of these services

The change, grounded in a view of stormwater as a resource rather than a problem, extends to the services that can be achieved through its use and not simply by controlling its quantity and quality, i.e., by taking care of floods and their contamination and pollution. The position as a component of the urban environment, attending the role of participating element of the urban water cycle and contributor in the achievement of the SDGs requires its accounting not only in economic terms but as a contributor of valuation aspects under other criteria, as of amenities: urban ecology, recreation and aesthetic attractions to the cities.

Concerning the role of rainwater as a resource, an idea present in the new paradigm of urban stormwater management, the epidemic of COVID-19 highlighted the need not only for policies to universalize water supply through traditional sources (surface water, groundwater and desalinated water) but also to implement policies to do so through the use of rainwater. For example, the political decisions to suspend supply cuts during the pandemic due to the default of low-income families, in several states in Brazil, as well as the free distribution of residential water tanks to this part of the population, in the state of São Paulo, demonstrate the need for policies designed to address events such as this or the combination of multiple events (floods and covid-19; dengue and covid-19; drought and covid-19), for which policy can and should consider the use of rainwater.

Economic aspects can be significant from several perspectives such as the savings provided by stormwater when compared to treatment or use permits from other sources and even expensive flood control structures, or the energy consumed by reuse water or desalination. The control of pollution at the source has been reported to be less costly than the traditional "end of the pipe" control.

The management structures, however, as they exist today, centralized and with few staff and expertise, are not sufficient for the decentralized service required, which demands adaptation of operational and organizational structures, the same happening with institutional structures such as laws, decrees, and regulation that lack experience in the matter (Montenegro 2017).

Concerning social actors, their participation is more necessary than in the centralized model in which decisions are made under technological viewpoints only, without taking into account other perspectives in management.

The consideration of interested actors from the point of view of resources and the financing of services necessarily brings about the perspective of their economic sustainability and the ways to make it feasible (Azevêdo 2019), causing policies to be designed "with the public" interested not only in the provision of services but in the planning of feasible actions and operations with economic sustainability over time.

Finally, the inclusion of little-used innovations in the policies, represented, for example, by real-time monitoring and remote operation technologies coupled with meteorological data and flood warning systems, also has the potential to include more efficiency and economy in the operation of the stormwater systems.

Where they exist, drainage policies are reflected in legislation and codes to a greater or lesser degree of detail and also in policies and practices for funding and financing. For the most part, the legal, institutional, organizational, and management structures are linked to urban flooding issues or pollution control issues. Despite all the available knowledge, whether sufficient or not, policy decisions on stormwater are at present very tentative, if not non-existent. The paradigm shifts from considering rainwater as a problem to an opportunity and a resource requires a policy change.

From this point of view, its use can result in a decrease in the needed amount of city water supply and even in the quantities of water to be treated and drained to the receiving water bodies.

The interrelationship between water supply and wastewater systems and urban stormwater is therefore clear, including concerning the revenue that each system generates, remembering that in many places wastewater revenue is linked to the drinking water supply and therefore a reduction in drinking water consumption through switching to rainwater has an impact on tax collection.

The obstacles related to the amount of funding as almost insurmountable barriers without advancing on the growth forecast of increased urban rainfall that already occurs and without quantifying them which makes the unquantified resource an absent element of policies.

For stormwater to become part of policies, it is essential to quantify it under a new paradigm in which it is considered as part of the solution, rather than a problem, and thus perceived by the population, as policies result from perceptions of reality that arise from conflicts between actors. Such perceptions, felt by policy and decision-makers, are not always based on reality, but on what is perceived by them. Thus, the academy has the task, initially, of quantifying stormwater, which should be done locally and, finally, contribute to the explicitness of the necessary paradigm shift in its various aspects, economic, social, and environmental, proposing technological and management solutions, and with the support of an actively participating society, so that the steps to be defined do not remain only on paper, as it happened with the MDGs.

There is already a concern about meeting the SDGs on several fronts, especially in the academy, which is reflected in a few publications and studies on the relationship between urban stormwater management and SDGs, about which some aspects were presented, which are, however, worthy of further reflection to increase knowledge and understanding of the relationship between stormwater and SDGs, pointing out the need for ways to measure its effects.

The road may seem long, but if the first step is not taken, which is quantification and planning that take into account stormwater, followed by the development of policies under the new paradigm, supporting them with institutions and structures, and the implementation under appropriate management and supervision, the provision of urban stormwater management services in a sustainable manner will be a very difficult and more complex task.

The existing examples and experiences gained over the years through Integrated Water Resources Management (IWRM) or Integrated River Basin Management (IRBM) policies that present lessons of success and failure and their difficulties in implementation (Tortajada & Biswas 2018) deserve to be well analyzed for policymaking under a new paradigm. There are also economic instruments based on the polluter pays principle, formulated by the OECD in 1972 and adopted by the Council of European Communities (CEE) in 1975, such as, for example, systems of fines and bonuses where fines must be higher than the profits gained from pollution and bonuses must be greater than the cost of pollution abatement, but these are instruments that require accurate information on the amount of pollution.

Finally, when considering the necessary participation of actors, one should not lose sight of the fact that consensus solutions should prevail, knowing that consensus does not mean unanimity, much less is carried out by actors on equal terms and resources, even if policies can be understood as resulting from conflicts of interest between participants with diverse interests and objectives in democratic contexts of participation, and more, that what we have today is the result of the application of successive public policy choices made previously, that is, it depends on the paths built by previous policies shaped within the optics of an old and aged paradigm.

As examples of successful Water Sensitive Urban Design (WSUD) policy implementation in Australia and the US, from which relevant numbers and conclusions can be drawn, can be cited: Etowah river Habitat Conservation Plan (HCP) Stormwater Management Policy, in Georgia, US; Portland's Downspout Disconnection Program, in Oregon, US; Nine Mile Run Rain Barrel Initiative, in Pennsylvania, US; Kansas City's (KC's) 10,000 Rain Gardens Initiative, in Missouri, US; Victorian Stormwater Initiative (and Clause 56, etc.) in Melbourne, Australia and Healthy Waterways Partnership in South East (SE) Queensland, Australia (Roy et al. 2008).

In terms of figures, one important aspect, perhaps the greatest, concerns the number of impervious surfaces, as these areas generate surface runoff that should be the target of public policies for the management of rainwater runoff that encourage its reduction over time, for example, by using the polluter-pays principle. Some examples are worth noting: 1) in the German city of Munich, since 1995 more than 4.5 million square meters of impermeable surfaces have been removed, resulting in a reduction of runoff by 3,000 million liters per year; 2) in Melbourne, Australia 608 GL (more than 300,000 liters per household) are generated on the streets and roofs in an average year with 650 mm rainfall. Policies designed with appropriate incentives, based on the polluter pays principle, can generate benefits for all, with reductions in Water and Sanitation Services (WSS) bills, for German cities, estimated to average 14% with the potential possibility of reaching 28% with optimization of stormwater use (Vietz et al. 2018).

## 4.5 Conclusions

This research discusses the policies regarding urban stormwater drainage and management services, where they exist, from a theoretical perspective, i.e., their relationship with existing institutional and regulatory frameworks, but also from a practical perspective, by addressing ongoing actions that seek to implement these policies in various locations and those global policies, such as SDG6, that should be present across the board in all countries.

The contribution of this chapter brings elements to reflect on what exists but also on what remains to be done to ensure that stormwater management services take their rightful place among the various urban services offered to the city's population. The existing gap, however, presents itself as demanding a paradigm shift that is necessary to make the provision of these services not just a wish but a reality.

Besides the conclusion that a paradigm shift is necessary and involves technological (e.g. source control), social (e.g. multi-stakeholder participation), economic (e.g. equitable and multi-source funding), managerial (e.g. hybrid centralized and decentralized), institutional, regulatory, and organizational (e.g., legislation and structures) and many others, there is a strong emerging view that policies for stormwater infrastructure and services must be premised on meeting multiple challenges simultaneously such as epidemics (e.g. dengue, covid-19) and other events that occur at the same time as flooding or therefore they must be flexible and embrace the concept of dynamic resilience of complex urban systems and the infrastructure that supports them.

By considering these concepts, political solutions might be more successful since they will have the capacity to adapt according to the evolution of events that demand them, abandoning the static and rigid vision of policies centered on conservatism and the maintenance of the status quo, whatever it may be.

# 5. REGULATION OF URBAN STORMWATER MANAGEMENT IS NOT A MATTER OF CHOICE, BUT OF PERFORMANCE

This chapter was published in Water Policy, an international peer-reviewed journal

doi: 10.2166/wp.2022.097.

## 5.1 Introduction

Policies, institutions, and regulation are part of a set of interconnected aspects that determine the incentives for the adequate provision of services. Policies provide the guidelines for action, institutions are the rules of the game, and regulations control their progress. The alignment of these three aspects around the goal of adequate service delivery allows the delivery of results desired by society, and when this does not happen, performance is insufficient to meet society's expectations (Mumssen et al. 2018).

Regulation can be defined as the control, exercised through self-regulation, contracts, or by a public agency over the activities that have value for society and involves establishing and ensuring the application of rules, whether economic as, for example, the setting of tariffs or, of service delivery and quality standards and may include goals of access and equity (Marques 2005).

Thus, the establishment of, for example, a pricing policy, supported by clear and fair rules, enables regulation to determine acceptable levels of tariffs to encourage demand management by users and contribute to efficiency gains by the providers.

Regulatory changes or reforms are introduced, as the environment allows, by diverse actors such as politicians, policymakers, senior government officials, and donors who choose what types of policy, institutional and regulatory interventions and what incentives are created from them.

The will of political actors alone cannot, however, promote the necessary long-term incentives, especially given the alternation between administrations (Kresch & Schneider 2020), but when regulatory incentives are aligned with local needs and institutional capacities, good results in terms of service delivery can be achieved (Mumssen et al. 2018a). The water sector may suffer from political interference such as, for example, the practice of reduced tariffs for electoral purposes, reflecting on the performance of service provision (Berg 2013).

This chapter aims to analyze some issues, not very frequently in the literature, related to the urban stormwater management service regulation. Its relevance is debated using international experience, particularly the Brazilian case study understanding that this discussion may contribute to achieving better performance results.

This chapter, based on a methodology of narrative analysis and case studies, refers to what exists in the literature and practice, and seeks to reach the subject of regulation from the side of its connection to political and institutional aspects and how the alignment between the policies, institutions, and regulation constitutes the enabling environment for the effectiveness of actions. It makes several contributions to the literature since there are few publications discussing these matters inexplicably. Besides the discussion and the relevance of the topic, it reviews and analyzes several international experiences of stormwater management regulation.

The chapter is organized as follows. Section 2 deals with the technical and economic regulation of stormwater systems. Section 3 presents the international experience in the regulation of stormwater systems. Section 4 analyzes in detail the Brazilian case study. Section 5 discusses the results and section 6 draws the main conclusions.

## 5.2 Regulation of stormwater systems

### 5.2.1 Quality as an objective - technical regulation

For a long time, attention on stormwater runoff was focused on solving quantitative issues, i.e., water volume. As a result of this view, the quality of stormwater runoff, plus the pollution it carries, only became important after studies demonstrated that runoff is a significant source of contamination of the environment and receiving water bodies.

Both urban runoff that occurs during wet periods and dry periods, such as runoff from agricultural activities (e.g., runoff from landscape irrigation), began to receive attention as sources of pollution produced by human activities.

The regulation of service quality emerged in many places based on this perception, linked to rainwater pollution, as it was in the USA in the 1980s, through Section 402 (p) of the Clean Water Act (CWA).

Quality regulation is generally carried out taking into account criteria and parameters present in laws and regulations, but also with the use of performance indicators, widely used since the 1990s (Bolognesi & Pflieger 2021), and should evolve in the stormwater sector, considering not only pollution aspects, but others related to the provision of urban services. These services include those associated with the well-being of cities, such as heat islands, water recreation, and urban beautification, classified as amenities, as well as the growing use of stormwater to replace traditional potable water uses, such as toilet flushing and the irrigation of green areas.

Technical regulation is now focused on managing the quality of the stormwater resource rather than the quality of the assets that transport or accommodate the physical volumes of stormwater and this is a result of the paradigm shift that is underway involving a shift in focus from quantity to quality management.

Economic regulation is affected by the requirements of technical and quality regulation as they affect costs and are transferred to tariffs within limits that are established by those responsible for economic regulation, as is the case in England and Wales (Molinos-Senante et al. 2020). In these countries, the body responsible for the economic regulation of water services is the Office of Water Services (OFWAT) while the quality regulation is in charge of two agencies: The Environment Agency (EA) and the Drinking Water Inspectorate (DWI).

### 5.2.2 Regulation as an incentive for efficiency - economic regulation

Economic efficiency and competition, although not an end in themselves, are instruments used to achieve economic and social development as ultimate goals. In the absence of competition, efficiency losses occur, as is the case of monopolistic markets such as water services, characterizing the so-called market failure, thus giving rise to the participation of the regulatory state to act to compensate for this failure, and circumvent, through regulation, the power of monopolies and the lack of competition (Marques 2010).

There are also other market failures, the so-called externalities, through which an individual suffers positive or negative effects of the activities of others. Network externalities, in which the existence of a network benefits the users who participate in it, occur in stormwater management systems, raising the issue of non-exclusion of access and non-rivalry in consumption, which allows the emergence of the phenomenon of 'free rider', in which users participate in consumption but not in the provision of services, leading to inefficiency.

Regulation can therefore be seen as a source of incentives for efficiency in service provision. One way to create these incentives is through a tariff policy that includes productivity earnings, which can lead to the formation of municipal consortia, especially when the municipalities realize that the economy of scale offsets the higher transaction costs of shared management (Narzetti & Marques 2021).

The determination of fair and reasonable tariffs, which consider the measurement of impervious areas over which precipitation occurs, is divided into two parts, i.e., the public, consisting of roads and public places such as squares and parks as well as public buildings, and the private, consisting of properties and buildings under a private domain (Ribeiro 2016), constitutes an economic incentive for the good use of soil and stormwater. By reducing soil sealing, it will be possible to obtain more efficiency in the use of infrastructure favoring its economic support from the perspective of the user-pays principle.  The use of rainwater as a resource, for example, for non-potable uses (toilet flushing and garden watering) is configured as another form of efficiency, through savings in the use of water supply, but also leads to a decrease in revenue related to water supply and wastewater tariffs, without a reduction in the use of sewerage infrastructure which can be configured as an economic inefficiency.

Besides that, the pricing structure where wastewater costs are estimated from water supply volumes does not encourage the use of rainwater as it leads to loss of revenue by reducing the water supply metering. The simplicity of revenue determination and tariff regulation from this type of pricing structure becomes a disincentive for efficiency when rainwater use comes into the picture. In this way, the price and tariff structure are also a barrier to universalization (Machete & Marques 2021), which is one of the objectives of regulation.

Another type of inefficiency arises from the exclusion of part of the population, implying a loss of economic scale and revenue. The tariff affordability should be considered so as not to exclude from the services those communities with lower incomes. As suggested by Gomes et al. (2008), in a calculation methodology aimed at financing urban stormwater systems, the water supply, wastewater collection, stormwater services, urban property, and land taxes should be limited to 5% of their income.

In the case of combined systems (wastewater and stormwater), the estimated portion of operation and maintenance costs incurred by stormwater is between 20-35% of the total and the amount of capital investments is around 30-50% of the total of these systems (Abdelmaki 1999). These values, if confirmed, according to the characteristics of each location and service provider, deserve to be segregated and accounted to the stormwater systems in terms of revenues to contribute to their economic support.

Furthermore, in combined wastewater systems, charging is done usually through a percentage on the water bill and this includes an estimated charge for wastewater services. In the absence of stormwater regulation, there is undue taxation of a service that is not provided, i.e., of stormwater regulation, which is yet another type of economic inefficiency.

At last, concerning regulation costs, the creation of stormwater regulation brings costs to providers that are reflected in the tariffs, through regulation fees, which can be significant for smaller municipalities with less than 10 thousand households, due to economies of scale. As pointed out, multi-sector regulation (joint regulation of several sectors such as electricity, gas, and water) could be an alternative to reduce regulation costs (Henten et al. 2003; Jordana & Levi-Faur 2010). Another alternative is the union of municipalities in regulatory consortia, which allow the dilution of costs among several municipalities, as is being proposed in Brazil.

## 5.3 International regulation of stormwater systems

### 5.3.1 The USA

The first country to be included in the study is the USA because it is where the federal regulation of urban stormwater is at a very advanced stage and where it has even pioneered the adoption of stormwater utilities as a way to organize the collection of funds to meet the increasing demands (since 1948, with the Federal Water Pollution Control Act –FWPCA) and strict legislation for the control of diffuse urban stormwater pollution in municipalities of all sizes.

In the USA, where stormwater utilities are widely used in the operation, management, and disposal of urban stormwater, regulation is originated from concerns over effluent quality and the contamination of receiving bodies and is mainly carried out through determinations issued by the Environment Protection Agency (EPA), since 1972, in accordance with the CWA. According to the EPA, the regulated area comprises 4% of the American territory but corresponds to more than 80% of the total population.

The concern with the quality and pollution of receiving water bodies was the motivation for the control of surface runoff that occurs mainly through the Municipal Separate Storm Sewer System (MS4), i.e., the transport systems of stormwater runoff, neither to be confused with combined systems (CS), nor with the systems of treatment of runoff effluents.

Discharge authorizations are a requirement for MS4 operators, as are stormwater management programs to prevent the input and conveyance of pollutants through the MS4. The programs detail the measures taken to control pollutants and state authorities are assigned responsibility for the National Pollutant Discharge Elimination System (NPDES) and in some locations this is carried out by the EPA as the responsible authority (Office of Water 2005; EPA 2010).

Since 1990, NPDES-compliant discharge permits have been required of MS4 operators in two phases: phase I, in 1990 (regions with more than 100,000 inhabitants; construction activity disturbing 5 acres of land or more; ten categories of industrial activity; 855 utilities; covered by 250 Individual Permits) and phase II, in 1999 (regions with less than 100,000 inhabitants; small construction activity disturbing 1 to 5 acres of land; 6,695 utilities; covered by State General Permits, but some states use individual permits). There are also three watershed permits covering 3 phase I and 40 phase II MS4 (Collins et al. 2012).

The development of phase II involved extensive stakeholder participation through consultations convened in a committee, constituted under the Federal Advisory Committee Act, with representatives of small entities and comments about the proposed rules submitted by more than 500 individuals and organizations during 90 days of public consultation.

In 2020, a survey collected information among the stormwater utilities. The regulatory requirements they were subject to, presented, as a result: 100% of the sample utilities are submitted to an MS4 - permit; 51% to total maximum daily load (TMDL); 49% to NPDES wastewater discharge permit; 10% to combined sewerage/excess/long term control program (LTCP); 7% to other special permits; 7% to sanitary sewer overflow (SSO) management plan; and 4% to integrated watershed permit (Black & Veatch 2021).

The survey, in terms of decisions priorities and levels of annual capital expenditure, pointed a score of 3.9 to regulatory compliance, on a scale of 1 to 5 (very strong), ranking third, after the management of stormwater conveyance infrastructure (1st) and flood control (2nd). For the item that contributes most to improving management, the expansion of regulations came fourth, with a score of 3.7, after funding adequacy (1st), awareness and support of society (2nd), and aging infrastructure (3rd).

There is state legislation authorizing the collection of stormwater tariffs by municipalities (84%) and the collection of tariffs is carried out on an area basis (according to 89%) with total areas or impervious areas computed (86%) and in the remaining 14% both types.

The computation of areas is based on aerial and digitized images of the impervious areas (54% of the answers), through the analysis of the footprints of the buildings from the tax systems (28%), a total gross area with an impervious factor (9%) and other methods (9%). The type of residential charging structure is based on: uniform tariffs (flat fee) (66% of respondents), calculated individually on a case-by-case basis (12%), and 22% stating that they use tiered tariffs in up to five levels. The average monthly residential tariff value, different in each state and city, varies from US$ 0.84 to US$ 25 (Black & Veatch 2021) and is related to aspects of geographic location, population density, and home value (Kea et al. 2016).

Register updating of total and impervious areas of units is carried out through GIS (Sydnor & Dunn 2015) in 59% of respondents.

Prices are considered by users as affordable or most affordable by 68% of respondents. Most of the utilities (68%) inform that they do not offer discounts.  There are exemptions, based either on legislation or on the utilities' own rules, for certain areas such as streets, roads, public spaces, or public passage (63% of the utilities) and several others.

Most utilities (79%) did not face legal challenges (Mcgovern &Hampton, 2016) and the remaining (21%), mostly were challenged by users in the non-residential categories (79%), regarding the collection of tariffs.

There is a provision of incentives for reductions in runoff volumes and peaks, water quality, education, direct discharge into surface water bodies, good practices (such as oil separation and sweeping), and zero discharges. The modalities of incentives are cost-sharing (60% of respondents), design assistance for best management practices (BMP) (50%), discounts for implementation (20%), reduced interest for loans (10%), and stormwater grants (30% of respondents).

In the USA, combined systems are designed to collect and convey large volumes of stormwater and wastewater while the sewerage system (SS) conveys only small amounts of rainwater and groundwater to treatment plants. This results in overflows that cause contamination of water bodies and returns to buildings with adverse health effects. These occurrences are due to blockages, bursts, defects in pipes and networks, pumping failures, or design and vandalism and are, according to the EPA, responsible for about 23,000 to 75,000 Sanitary Sewer Overflows (SSOs) events annually, disregarding the returns to buildings (EPA 2022).

Concern about these events has led stormwater management programs to take them into account by setting as one of their objectives the reduction of pollutant discharges to certain levels considered to be the ‘maximum practicable’ or the maximum extent practicable (MEP), protecting water quality and complying with the CWA.

Phase II MS4 programs consider stormwater as point sources of discharge and rely on six joint minimum objectives to achieve the MEP: education and outreach on stormwater impacts (Biehl & Buechter 2011), societal engagement, elimination of illicit discharges (Irvine et al. 2011; Derrick & Moore 2015), construction of runoff controls, post-construction stormwater management, management in new and rehabilitated developments, and implementation of best practices and pollution prevention for municipal operations.

#### *5.3.2 Europe*

In Europe, stormwater management falls under the Water Framework Directive (WFD) 2000/60/EC - eco-centric - and also the Floods Directive (FD) 2007/60/EC - human-centric - (Jensen et al., 2020), the latter integrated with the former to promote integrated management by catchment, but with specific variations in each country, produced by a mix of regional and central agencies, but not always adopted in local legislation. The focus, however, refers to aspects of water quality and quantity, mainly directed at the receiving water bodies, leaving the approach on the origin and generation of urban runoff to a secondary level, without even mentioning the term ‘stormwater’ or, in a more detailed way, the economic aspects of regulation, such as the polluter-pays principle for stormwater management systems with the sharing of responsibilities for the generation of runoff in qualitative and quantitative terms.

The WFD refers to drainage only twice (Jensen et al. 2020), firstly when dealing with the artificialization or modification of surface water bodies that suffer from the effects of rainfall-runoff draining onto land, and secondly when identifying potential groundwater pollution through recharge with runoff from rainfall drained artificially into groundwater.

In Germany, there is increasing decentralization in urban stormwater management, and regulation is carried out by municipalities using mainly incentive instruments such as tariffs and discounts on usage and compulsory connection, following the establishment of local and national laws and codes and multidimensional objectives. Decentralization receives, however, questioning due to the loss of economies of scale and the high transaction costs involved (Bedtke et al. 2019). The disconnection of impervious areas contributes to the better performance of the systems and is an important aspect to be regulated. In areas of dense, consolidated urbanization, however, it encounters many obstacles. The city of Berlin, which has a separate system, was analyzed with the use of GIS technology and the result concluded that it is possible to easily disconnect 30% of the impervious areas (Sieker & Klein 1998).

In France, the existence of some 36,000 municipalities makes it difficult to comply with the principle of subsidiarity, especially regarding urban stormwater where ownership and problems are under the responsibility of the communes and therefore the control and regulation of services lie at the local level. Nevertheless, water agencies are responsible for setting charges to users for water use, leading to the financing of wastewater and stormwater infrastructure with resources obtained from water bills, which raises questions as the French option is for a separate wastewater system and there is also a provision in the law for associations of municipalities to charge for stormwater management (Barraqué 2013).

### 5.3.3 Australia

Australia, which has undergone a long transition process concerning urban water over the last decades, highlights the fact that policies are not implemented on their own and depend on instruments such as regulation to make them work. Like policy frameworks, regulation is part of a set of factors conditioning actors' behavior and can be classified in two formats: ‘soft’ like policy frameworks or best practice guidelines, which only encourage behavior, or ‘hard’ like command-and-control structured regulation, which compels it. The Australian policy shift towards water-sensitive urban design (WSUD) was characterized by several phases and the coexistence of ‘soft’ and ‘hard’ regulations. Initially, there was a successful phase with an institutional reversal creating the perception that transition processes of complex systems require regulation and attention in their trajectories as was the case of the transition from the traditional model of urban stormwater management in South-East Queensland to WSUD (Werbeloff & Brown 2016). Anyway, in the most important urban areas such as Sydney metropolitan area in New South Wales or the Melbourne region in Victoria, the multisector regulators set tariffs and quality guidelines for the stormwater systems (by Independent Pricing and Regulatory Tribunal - IPART in the former and Essential Services Commission - ESC in the latter).

### 5.3.4 Other regions

In Latin America regulation is almost non-existent and even in Chile, considered as an example of water regulation, there is no specific regulation for stormwater.

In China, projects implemented locally at the municipal or sub-provincial level about the Sponge Cities Initiative (SCI) program, a national initiative for the construction of sponge cities, conceived by the central government under the Low Impact Development (LID) concept, which has edited a preliminary technical guideline, aims to establish a regulatory structure, but still lacks financing and management models such as Public-Private Partnerships (PPPs) arrangements, which, despite being encouraged (Jiang et al. 2017), do not yet have mature legislation and regulation (Zhang et al. 2019). In the prosperous city of Ningbo, for example, which is undergoing rapid expansion, only one PPP project was initiated until 2018, according to government information (Qi et al. 2020; Griffiths et al. 2020).

## 5.4 Regulating Stormwater Systems in Brazil

### 5.4.1 Introduction

In Brazil, according to legislation (decree nº 7.217/2010), urban stormwater management services include urban drainage, urban water conveyance, detention and retention of urban stormwater to dampen flood flows, and treatment and final disposal of urban stormwater.

The public service of urban stormwater management, being a water service of local nature, i.e., a public function of common use to be provided locally, is owned by the municipalities and, therefore, its provision is performed directly by the municipality or by third parties under delegation (law nº 11.445/2007).

However, even though it requires a specific administrative structure and its own revenues for its proper functioning, most municipalities provide services directly without disentangling this service from other municipal functions, and accounting for their costs and other resources jointly. Besides, they usually do not count on dedicated revenues, legal instruments, and exclusive staff (Baptista & Nascimento 2002).

Infrastructure related to urban stormwater management services is incorporated into the municipal infrastructure and depends on the overall municipal budget for maintenance and expansion, or on state and federal resources which in turn have priorities that are not always identical to those of the municipality. Road system is part of the municipal urban stormwater systems, and as the latter is often considered part of the former, is included in its budget (Nascimento et al. 1999).

In Brasil, the coexistence of municipal master plans, WSS plans, and urban drainage master plans is a mandatory requirement for municipalities to obtain resources from other federal entities (Decree nº 7.217/2010. Furthermore, in addition to the dialogue between all these municipal plans, it is necessary integration with plans for water resources, preservation areas, hydrographic basins and health plans, activities that cannot be delegated (law nº 11.445/2007). The regulation, although a municipal attribution, as well as the provision, can be delegated to other entities including consortia (Oliveira & Marrara 2017).

Thus, the planning activity is carried out in a sector-specific way, producing an unnecessary fragmentation despite the intimate correlation between the water services (e.g., wastewater and stormwater). This is an issue that deserves to be overcome towards integrated planning, according to the vision of integrated urban water cycle management (Pinheiro 2019).

The integration and complexity of urban stormwater management involve aspects related to the road system, land use and occupation, management of permanent preservation areas, protection of aquifer recharge areas (Caprario et al. 2019), and flood mitigation, as well as care for endemic areas related to various diseases (malaria, dengue).

### 5.4.2 The role of the National Agency for Water and Wastewater (ANA*)*

Recently the regulatory landmark of water services was updated by law no. 14.026 of 2020 intending to speed up the universalization of water services in Brazil. This new law was prepared in such a way as to allow for the standardization of existing experience and knowledge to make the universalization of services feasible and provide for greater involvement of private capital given the reality of fiscal stress and insufficient public resources to meet the necessary demands.

Among the novelties, law nº 14.026/2020 renamed the National Water Agency into National Water and Sanitation Agency (ANA) creating a federal regulator for the water services. Among its responsibilities, ANA will establish reference standards which are guidelines that the subnational regulatory agencies need to comply with.

Concerning stormwater services, ANA will define guidelines for economic sustainability in urban stormwater management that should be adopted by the sub-national agencies. These guidelines should aim at reducing costs, improving quality, and expanding the coverage of existing stormwater networks, all of which are aspects that depend on information about what exists, including how stormwater management is perceived by the population.

After listening to all stakeholders, such as sub-national agencies, through public hearings reference standards will be prepared. The adherence to reference standards will not be mandatory but it will be a condition for access to public resources. The reference standards will be submitted to a regulatory impact analysis (RIA) before coming into effect and will be complemented with manuals, guides, studies, and training courses. It is also up to the ANA the challenge of making the plans for water resources (basin level) and urban stormwater management, rainwater and solid waste (municipal level) compatible (ANA 2020).

This recent legal determination, (Brasil, 2020), to assign responsibility to ANA for the elaboration of national reference standards regarding water regulatory issues in Brazil has raised expectations of improving the performance and results of the sector. As to this, however, the observations made for water services, by Berg (2013), are pertinent, including as to urban stormwater management:

‘...sector regulation must be embedded in an adequate and consistent institutional framework to have a positive impact on performance. Sector regulation alone is no guarantee of performance improvements in water supply and sanitation services. The case studies and empirical analysis suggest that without significant changes in the institutional environment, typical regulatory tools will not be effective. This finding is of concern, especially for developing countries, as it means that the creation of a regulatory agency may raise expectations, but ultimately the agency's rules may not be of improving the performance of the provider(s), without additional politically difficult initiatives being taken.'

### 5.4.3 Regionalization

To allow the universalization of services, taking into account the knowledge that a large part of the municipalities have deficits and receive subsidies from the remaining by cross-subsidization from those with surpluses, the creation of 'blocks' of municipalities (regions) was encouraged by the new law aiming to create economies of scale that may become highly sustainable economically.

The design of 'blocks' considering only water and wastewater, without taking into account the costly infrastructure of urban stormwater, makes the intended integrated vision suffer from the exclusion of a component that, in most countries, has no longer been considered as 'outside accounting', due to costs, but especially to the effects of increased rainfall with climate change, and its costly consequences. This non-inclusion, or just its consideration at a third level, can be deemed a mistake that we cannot give ourselves the right to incur given the damages that the political, economic, and socio-environmental consequences may cause shortly.

From the aspect of cost recovery, if we want to seriously consider the economic balance of the 'blocks', also the socio-economic-environmental quality existing today in the territories and that which is intended to be achieved with universalization must be taken into account.

Quantification, therefore, is not an easy task, but one that must be faced under penalty of incurring in the construction of unsustainable 'blocks', whether economically or politically, calling into question the strategy of universalization with the use of regionalization of solutions or leading to enforcement of authoritatively decided solutions, under §3º article 52º of law nº 14.026/2020, which is in opposition to the principles of democratic participation present in the legislation (law nº 11.445/2007).

### 5.4.4 State Regulation by Agreement - ARSESP in the Municipality of São Paulo

In the municipality of São Paulo, the largest urban agglomeration in South America, the regulation of water and gas is carried out through a multisector agency, the Water and Energy Regulatory Agency of the State of São Paulo - ARSESP (São Paulo 2007). The investments in the municipality are defined jointly by the State of São Paulo and the Municipality of São Paulo, according to the Municipal and State Plans through a management committee composed of representatives of the two federative entities.

By means of law nº 14.934 of the municipality of São Paulo (Prefecture of São Paulo, 2009), an agreement was signed between the municipality of São Paulo, the State of São Paulo, ARSESP, and the Water Company of the State of São Paulo (SABESP), aiming at regulating the shared offer of water supply and wastewater services in the municipality of São Paulo, provided by SABESP, valid for 30 years, extendable for an equal period, in which a minimum of 7.5% of gross revenue from services, after deduction of certain social taxes, such as

Contribution for Social Security Financing (COFINS) and Programs of Social Integration and Formation of Public Servants' Equity (PIS/PASEP) is allocated to the Municipal Environmental Sanitation and Infrastructure Fund (FMSAI), and 13% is earmarked for investments in water and environmental actions.

The FMSAI is accounted for and operated by the Municipal Housing Secretariat and managed by a council that must apply the resources according to the investment priorities contained in the Municipal Sanitation Plan, as shown in Figure 5.1.

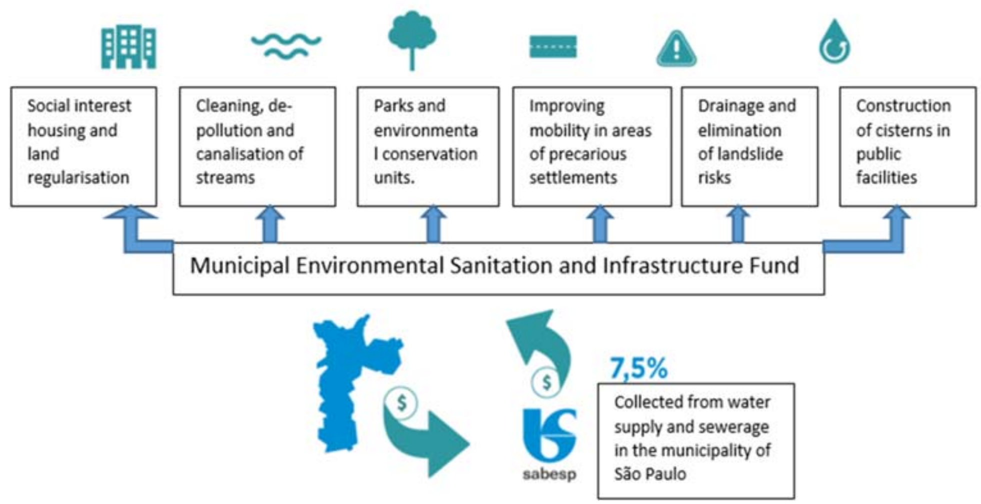


Figure 5.1 - Municipal Environment Sanitation and Infrastructure Fund (https://www.prefeitura.sp.gov.br/cidade/ secretarias/habitacao/fmsai/apresentacao/index.php? p=145635,adapted).

The fund's actions (Figure 5.1) focus on aspects related directly or indirectly to urban stormwater and water management, such as cleaning, depollution, and channelization of the water lines, implementation of systems to capture, store and use rainwater in public facilities and areas of influence or occupied predominantly by low-income populations, implementation of linear parks and areas to protect natural conditions and of water production, land regularization and social interest housing, and improvement of mobility in areas of precarious settlements.

There are positive aspects in the FMSAI institutional organization, especially regarding the maintenance of a permanent source of funding, although this is not exclusive to stormwater management actions, sharing resources with other areas, such as housing. Within the scope of the FMSAI, however, the integration with other areas, such as health, environment, planning, water resources, land use, land occupation and urban policy (some of which have seats on its Steering Committee), is seen as a positive factor, since water services are transversal and correlated with territory and society (Montenegro et al. 2021).

The linking of revenues from the stormwater management component to the water supply component, however, deserves to be analyzed to verify if this form is not a limiting factor to the development of actions that are required for the efficiency of planning, management, and its regulation and inspection.

### 5.4.5 Stormwater regulation in the Federal District (Brasilia)

The lack of institutionalization of stormwater management services in Brazil is generally reflected in the absence of public entities specializing in the provision of these services, specific revenues to fund the activity, few urban stormwater master plans integrated with municipal water and sanitation services (WSS) plans, and virtually no regulatory activities.

One of the few exceptions to this general picture can be found in the Federal District (Brasilia), where the Water and Power Regulatory Agency (ADASA) has been developing activities aimed at encouraging the structuring of urban stormwater management services, including aspects related to economic regulation, with support from the tariff collection based on impervious areas and taking into account land uses and the population's ability to pay, according to the legislation in force.

The barriers to the implementation of the proposals issued by ADASA, however, do not differ from the rest of the municipalities regarding the lack of specialization of the body in charge of the stormwater management, i.e., Urban Company of New Capital (in Portuguese, the Companhia Urbanizadora da Nova Capital - NOVACAP). This company does not have specialized staff and a concession contract and competes with other bodies for resources from the general budget of the Federal District (FD). Therefore, it finds obstacles to the maintenance of services in an adequate way, a fact that is reflected in the few investments for the maintenance and replacement of the dedicated stormwater infrastructure with the consequent and frequent flooding.

Concerning the planning, the existence of an Urban Stormwater Master Plan (PDDU) and a District Basic Water and Sanitation Plan (PSBDF) are important instruments, but in the absence of permanent sources of funds, they are of little use.

Ongoing efforts towards the quantification of impervious areas, whether public or private, will allow the individual estimation of each lot contribution to runoff to the existing public network and thus, also the calculation of the amounts necessary for the materialization of the user-pays principle and the economic sustainability of stormwater systems. The establishment of individualized tariffs with possible reductions to owners who have retention devices or other ways of using rainwater that falls on their lots, or even disconnection from the networks, may be possible and is a reason for regulation by the agency, as they constitute incentives to reduce runoff and associated costs.

The portion corresponding to the rainfall occurring in public areas, such as roads, streets, squares, and others for common population use and public buildings should receive resources from the public budget. ADASA's study has computed that results for the percentage of impermeable areas in the Federal District of Brazil are 49% for private areas and the remaining 51% for public areas of the common use of the population (Montenegro 2019).

Thus, the importance of regulation is visible in the actions and proposals made by ADASA, in which the regulatory agency develops relevant contributions by identifying and qualifying the alternatives for the institutionalization of services through the improvement of the organization of service provision and the study of the charging model to be adopted. This latter involves not only the costs of the system, but also the quantification of social tariffs, cross-subsidies, and other parameters necessary for the economic and quality of service regulation of the urban stormwater management in the Federal District.

Finally, the State's performance in its role as a planner, a regulator, and responsible for the activities at all levels of government and as a participant in the financing and management, following constitutional precepts, does not escape the focus of the debate on social democratic rights to water and also economic efficiency (Neto & Camkin, 2020).

### 5.5 Results and discussion

The absence of regulation as a performance leverage tool that should be part of stormwater management cannot be attributed to the lack of an object to be regulated but to the absence of its institutionalization and of policies arising from the fact that it is not present in the mindset of political decision-makers and population, as an issue requiring public policies and consequently with a gap in its provision of resources (Werbeloff & Brown 2016). As in other sectors, we may question the ideal moment to implement its regulation: before, during, or after the institutionalization of the activity.

This is, however, a false question, which may arise due to the erroneous view that only private concessions should be regulated. In its origin, as it is known today, regulation was originated in the USA and in the water sector in England and Wales, linked to privatization issues. However, in Chile, for example, the regulation of water services which is considered successful was initiated before their privatization (Ducci 2007), but until now without stormwater regulation. The regulation idea has evolved, and examples regarding the forms and moment of implementation of regulation show that there is no general rule, but that, as well as the allocation of resources, it must always be present for better performance of the systems. In this scope, well-regulated private sector services, in addition to economic issues, may contribute to universalization. However, well-designed stormwater regulation also involves regulating the performance of the public sector which, as we have seen, is responsible for a large part of the impervious areas of the territories, consequently by a large part of urban stormwater.

Regulation is based on two pillars: economic efficiency and quality of service. Economic efficiency regulation requires that are plans, contracts and resources invested. Both require planning, contracts and resources invested.

Stormwater management is an intermittent service and it is not always seen as important (Dobbs et al. 2013). It is only when disasters occur that political decision-makers are present, but with a short-term vision that often only exacerbates the perception that only specific actions and funds earmarked for that specific event are the solution.

The institutionalization of economic and financial support for stormwater management systems requires a permanent flow of dedicated revenues, as is the case with stormwater utilities in the USA (Campbell & Bradshaw 2021). It also implies the existence of regulation as a means of making resource flows more efficient economically and politically, according to defined policy goals, with equally explicit objectives of urban economic development (infrastructure growth and maintenance), environment (river clean-up), and social (well-being, people participation and access to systems) seeking to bring equitable welfare to the entire population.

The economic regulation can meet multiple objectives as is the case of social tariffs in Brazil, Chile, Uruguay (Narzetti & Marques 2020), Spain, and South Africa. Quality service regulation also show environment good results, like in Australia and the USA, or directly linked results to the performance of stormwater infrastructure networks, as occurs in Germany with the incentives for participation of the private sector in the disconnection (Sieker & Klein 1998).

In urban stormwater management systems, there is, all over the world, a multiplicity of situations and formats of management and regulation (Table 5.1) according to different stages of the paradigm shift underway in the sector. In Brazil, for example, the regulation of urban stormwater management systems is in its infancy, with few, diverse and fragile rules drafted or in preparation, such as the future reference standards of ANA, awaiting experimentation and results. Brazil, for example, can still shift paradigm and put stormwater management as a priority. So, aligning regulation in PIR is key to increase organization and performance.

China is experimenting with the institutionalization of the LID concept through the idea of sponge cities in 30 cities, but with results expected in the medium (2030) and long term (one generation). The country seeks to encourage PPP arrangements but does not yet have models for this (Jiang et al. 2018).

In other countries, such as the USA, the rules already have results from older applications, despite the great diversity of alternatives and Australia can be considered at an advanced stage, with broad voluntary participation of like-minded people including regulators, but with its own dynamics and diversity of regulation in each location (Radcliffe 2018).

The general panorama of stormwater management, evidenced by the international and Brazilian examples, presented as a result in Table 5.1, shows that there is no influence of Gross Domestic Product (GDP) per capita, as it might seem, on the alignment between PIR. In the same way, one cannot affirm that the smaller or larger participation of the private sector, through the privatization of providers, as is the case in the UK, has an impact on PIR alignment, the same occurring with decentralization as in France and Germany, although in different formats. In Germany, a country where decentralization has a significant importance, good results are highlighted in some areas, such as Munich, which, however, deserve a deeper analysis of the institutional and regulatory structure. The two countries where the alignment is most noticeable (Australia and the USA), still partially, with some gaps in aspects and locations, leave questions to be answered, such as the how path dependency or institutional inertia contribute to existing alignments.

Table 5.1 – GDP per capita of some searched countries and PIR alignment.

| Country (US$ GDP/capita in 2020)[a] | Policy (P) | Institutions (I) | Regulations (R) | PIR Alignment |
|---|---|---|---|---|
| U.S. (63,206.5) | Pollution control, Low Impact Development – Best Management Practices (LID- BMP) | Environment Protection Agency (EPA) rules, Stormwater Utilities, Federal Acts, State and Municipal Laws | EPA Rules, MS4, NPDES, State and Municipal Laws | ned in many es, but not all aspects |
| GERMANY (42,252.7) | Pollution control and multiobjectives | Federal, Local (Länd) and Municipalities laws and Water Companies rules, Verbänd (river managers) guidance's, Water Framework Directives | Self-regulation | Not aligned |
| FRANCE (39,037.1) | Flood-control | Communes(Municipalities)laws, 6 Agences de L'Eau rules, Watershed institutions, contractual rules | Contratual arrangements | Not aligned |
| UK (41,059.2) | National funding of reduction flooding vulnerability, Sustainable Drainage Systems (SuDS) | Water Services Regulation Authority (OFWAT), Environment Agency (EA), Drinking Water Inspectorate (DWI) and Municipalities rules. Flood and Water Management Act, 2010 | No stormwater regulation, just Construction Industry Research and Information Association (CIRIA) – SuDS Guidance[b] | Not aligned |
| AUSTRALIA (51,680.3) | Water Sensitive Urban Design (WSUD) | Multisector Regulators, IPART (Independent Price Authority Regulatory Tribunal) and ESC (Essential Services Commission) rules | Each state has its own regulatory body and its own rules | Aligned in some places |
| CHILE (13,231.7) | Integrated Water Resources Management (IWRM) | Superintendencia de Servicios Sanitários (SISS) rules | No stormwater Regulation | N/a |
| CHINA (10,4343.8) | Sponge Cities Initiative – Low Impact Development (LID) | Technical Guidelines | No stormwater Regulation | N/a |
| BRASIL (6,796.8) | IWRM | Municipalities Laws, All levels Agency Independent Regulators rules | Few initiatives | Not aligned |

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On the performance side, what can be said is that economic and quality regulation in the two countries, where greater alignment is observed, show positive results, both in terms of economic and environmental sustainability, without meaning that they cannot further improve.

### 5.6 Conclusions

The study has limitations because stormwater is a service of local responsibility, but subject to a multitude of PIR spread over all levels of administrative organization of the state, in all localities, which have distinct institutions, making it impossible for the literature to contain everything, and local research in many cities is extremely difficult, time-consuming, and costly. This is one of the reasons why the text contains many details from places where we have had greater knowledge, as is the case in Brazil.

The search showed that in one way or another, by contract or by agencies, or even in their absence (self-regulation), the owners, i.e., the municipalities, exercise control over urban stormwater management systems. Policies, institutions and the institutionalization of the regulation and of resources allocation to urban stormwater management systems are a weak part of the organization and determination of performance, given the increasingly evolving demands and the lack of PIR alignment.

The greater or lesser degree of alignment between policies, institutions (formal and informal), and regulation, as we tried to demonstrate with examples, according to each local reality, and the related performance of service provision, was not very well confirmed, but in both countries where some degree of alignment was found the perceived performance is high.

In the current situation, regulation, as well as the attention given to the institutionalization of urban stormwater services, is practically absent in many countries (Table 5.1). So, aligning regulation in PIR deserves to be better considered, firstly because regulation is a question of efficiency and resources saving, secondly because efficient management and use of existent infrastructures also has the potential to reduce the costs of climate changes improving capacity to economic grown and development.

The lessons provided by the regulation of various sectors, together with the few initial experiences concerning urban stormwater, provide starting points for the evolution of the subject, which is expected to grow in the coming years. These are questions for near future research studies.

It should be noted, however, that the regulation of the stormwater sector is much more complex than that of other water and public services due to its hybrid public-private character with inseparable interaction between the two, as regulation should cover both public and private aspects of sealed territories and the water that falls on them, making it impossible, for example, for financing systems to be covered by only one part of this complex whole.

In places where the universalization of services has not yet been achieved and in which economic and social inequality is a striking feature, as is the case in Brazil, economic regulation should seek not only purely economic objectives and goals, but others that imply the inclusion of the excluded and equity in access and use of urban water systems.

Universalization as a policy goal and regulation as an instrument to achieve it, as intended by the new Brazilian water legal framework, should be built taking into account solutions for urban water in slums and the peripheral urban fringes, located at the urban-rural interface.

Finally, just waiting for the establishment of institutions that will take care of the regularization of land title or the implementation of the entire infrastructure to meet urban stormwater demands means abandoning the goal of water services for all, the Sustainable Development Goal 6 (SDG6), perpetuating exclusion and inequality with obvious consequences for urban social cohesion and society inefficiency in many parts of the world.

In future studies, it may be interesting to choose places with recognized stormwater systems performance to verify what the PIR are and how they work, so that comparisons can be made, without leaving aside the fundamental question of the mechanisms instituted for the contribution of resources and their magnitudes.

# 6. AEDES EGYPTI – INSIGHTS ON THE IMPACT OF WATER SERVICES

This chapter was submitted to an international peer-reviewed journal.

## 6.1 Introduction

With the pandemic of COVID-19, health issues have gained prominence all over the world as has never been seen before. It changed all existing priorities and strengthened the public policies of all countries worldwide, including the provision of essential public services, such as water services (WSS), comprised here by water, wastewater, and stormwater. Although the impact of this pandemic on public health and the economy of different countries and regions is very high regarding the number of deaths, the impact of other diseases should keep having attention, such as those resulting from leptospirosis, malaria or the Aedes Aegypti mosquito, which among other diseases causes dengue fever (Brady & Smith 2021).

Dengue fever is classified by the World Health Organization (WHO) as one of the 17 neglected diseases, treatable and not curable, with old diagnostics methods and inadequate treatments (WHO 2017). For these reasons, dengue fever demands investments and developments to become simpler and more effective to treat but it has not aroused much interest from the pharmaceutical industry. In several countries in South America, Africa, and Asia, such as Brazil, this is a major disease, impacting substantially the health of the population and the economy.

The main dissimilarities between these diseases and COVID-19, which will make all the difference, are that the former mainly affects the countries with low or average income and whose contamination is less widespread around the world. Furthermore, it is mainly associated with the lack of WSS, which does not affect the richest countries. In Brazil, dengue fever is an endemic disease and has the highest incidence in absolute numbers in the country, but there is no specific treatment or vaccine (Rosenblatt 2020).

In the recent (2019) Brazilian epidemic, the existence of dengue, Chikungunya, Zika, and urban yellow fever demonstrated the presence of the vector mosquito - Aedes Aegypti (Consoli & Oliveira 1994). In urban areas, these vectors find available water for their breeding sites from two distinct origins that obey logic related to WSS issues. First, the open buckets and containers used in periods of intermittent rainfall or irregular water supply (Caprara et al. 2009); and secondly, in rainwater puddling sites due to problems in stormwater management systems.

This research will discuss the incidence of Aedes Aegypti-related diseases and the availability of urban WSS, using Brazil as a case study. In this country, urban water supply coverage reached 84,1% (93,4% in urban) in 2020 (Brasil 2021a), however, a relevant share displays a poor quality of service: untreated water, lack of continuity (195,6 thousand systematic interruptions of six or more hours), and high-water losses of 40,1% (Brasil 2021a). The situation of wastewater is even worse: 55 % of the total population has wastewater collection (63,2% in Urban) and only 47 % is treated. The figures for urban waste are not better: 92% of the population has waste collection, but just 59,5% is disposed of adequately. The panorama is worse if the rural population is included since it still represents around 15% of the total population (ABRELPE 2020).

Urban WSS and solid waste are under the responsibility of Brazilian municipalities that plan and can provide directly or delegate them to a State or private companies. With less or more autonomy and corporatization, a contract must be signed between the municipality and the operator, being regulated by an external independent authority (Narzetti and Marques 2021b).

Table 6.1 shows the heterogeneity of WSS and urban solid waste availability in the country. While South and Southeast display coverage levels and quality of service almost similar to ones in high-income countries, North and Northeast show numbers close to low-income countries.

Table 6.1 - WSS and solid waste services by region.

| **REGIONS** | **South** | **Southeast** | **Northeast** | **Midwest** | **North** | **Total (% or $10^6$ inh.)** |
|---|---|---|---|---|---|---|
| Waste collection (ABRELPE 2020) | 95% | 98% | 81% | 94% | 81% | 92% |
| Water supply (WS) (Brasil 2021a) | 91% | 91,3% | 74,9% | 90,9% | 58,9% | 84,1% |
| Wastewater collected (Wtc) (Brasil 2021a) | 47,4% | 80,5% | 30,3% | 59,5% | 13,1% | 55,0% |
| Wastewater treated (Wtt) (Brasil 2021a) | 46,7% | 58,6% | 34,1% | 58,5% | 21,4% | 47% |
| Total pop. ($10^6$) (Brasil 2011) | 27,3 | 80,3 | 53,08 | 14,05 | 15,86 | 190,59 (210,72*) |
| Pop. without WS ($10^6$) | 2,46 | 6,98 | 13,32 | 1,27 | 6,51 | **30,30 (33,50*)** |
| Pop. without Wtc ($10^6$) | 14,35 | 15,65 | 37,00 | 5,69 | 13,78 | **85,76 (94,82*)** |
| Pop. without Wtt ($10^6$) | 14,55 | 33,24 | 34,98 | 5,83 | 12,46 | **101,01 (111,68*)** |

*Estimated population – IBGE – 14-11-2019

A low level of investment explains the gap. Brazil, with 213 million inhabitants in 2021 (IBGE) invested in the last years US$2400 million/year, or under 1USD/per capita/month, so to obtain universal access to the WSS until 2030, however, it requires three times more, according to the National Plan of Basic Sanitation, or somehow an even higher amount (Pinto et al. 2015).

In Brazilian municipalities, stormwater management is not institutionalized and does not own a specific budget and skilled staff (Novaes and Marques 2022). Of the 73 regulatory agencies with responsibility for WSS regulation, just one regulates stormwater management (ADASA, in Brasilia), so the programs are uncertain and unpredictable, which hinders its planning and preventive actions.

These official indicators, which show an adverse situation, did not significantly improve in the last two years and are much worse since they do not include a large part of the peri-urban population (Narzetti & Marques 2021a). Furthermore, most of the municipalities are not endowed with urban stormwater management, which is really the ugly duckling of WSS since it is a service of intermittent use. Indeed, its importance is contingent on rainfall and other local characteristics, such as topography, impervious areas, and WSS budget and city policies. This chapter assesses the importance of urban WSS coverage in mitigating the proliferation of the Aedes Aegypti mosquito and consequently Dengue fever, Chikungunya, and Zika. Particularly, we analyze the impact of urban stormwater infrastructure, a scarcely researched issue.

In Brazil, the States of São Paulo (SP), Paraná (PR), and Rio de Janeiro (RJ) are highly urbanized and wealthy (with more impermeable areas), with high rates of WSS coverage, highlighting a very high number of dengue cases. Thus, to understand the extent of those assumptions, we use rich and detailed data from official Brazilian institutions to correlate urban WSS and Aedes Aegypti-related diseases. The assessment of urban stormwater infrastructure and other WSS variables at the municipal level, including 4100 Municipalities covering 89% of the population, as far as we know, has never been exploited, being innovative and bringing several contributions to the literature.

After this introduction, section two highlights urban WSS and health considerations. Section three details the methodology used. Section four analyses and correlates the Dengue, Chikungunya, and Zika cases with urban WSS infrastructure and other variables discussing the results obtained. Finally, section five displays the concluding remarks and some policy implications.

## 6.2 WSS and public health

Cairncross and Feachem (1993) proposed a classification of infectious parasitic diseases that are potentially determined by the environment, which they called diseases associated with poor sanitation (DAPS). The term should be understood in the context of lack or insufficient sanitation (water services), in addition to poor housing conditions. The DAPS are classified as follows: (i) fecal-oral transmission diseases (e.g., diarrheal); (ii) vector-borne diseases (e.g., dengue); (iii) water transmitted diseases (e.g., leptospirosis); (iv) diseases associated with hygiene (e.g., conjunctivitis); and (v) geohelminths and taeniasis. This classification can contribute to the creation of health protection programs, as well as to the assessment and development of public sanitation policies (Siqueira et al. 2017).

Aedes Aegypti mosquitoes are responsible for transmitting Dengue, Chikungunya, Yellow Fever, and Zika (e.g., baby microcephaly), and to protect the population the socio-economic conditions that favor the presence and proliferation of vectors must be understood (Johansen et al. 2016).

WHO mentions poor WSS as a serious life threat and stated that, for each dollar invested in treated water and wastewater collection, 4.3 dollars are saved in terms of health expenditures (WHO 2014). The global incidence of dengue increased in recent decades and half of the world's population is at risk, WHO estimated 100-400 million infections each year (WHO 2020) with significant costs (Lee et al. 2019) and a major economic impact, particularly in developing countries (Oliveira et al. 2019). From 2001 to 2009, diarrhea and dengue were responsible for more than 93% of hospitalizations caused by DAPS in Brazil and the average annual costs of hospitalizations were responsible for 3,3% of total Brazil's Single Health System (SUS) expenditures involving hospitalizations (Teixeira et al. 2014).

For example, Campinas municipality (1.2 million inhabitants, 794 Km², GDP 13,573 USD/capita, (IBGE 2019)) follows a recurrent pattern of urbanization in Brazil and Latin America where inequality in the distribution of services among social groups, living in different intra-urban spaces, provides favorable conditions for vector proliferation (Johansen et al. 2016; Barreto 2017). There were dengue fever outbreaks in 2007 and 2014. The improper waste urban destination and the irregular and non-universality of water supply to this day are common features in Brazilian urban centers (Brasil 2021a, b). In a study carried out in Rio de Janeiro, where pesticides are widely used to combat mosquitoes inside homes, the presence of these pollutants was detected in the urine of pregnant women and new-born babies (Fróes-Asmus et al. 2021).

### 6.2.1 Aedes Aegypti/Aedes Albopictus/Culex

Arboviruses are diseases caused by an arbovirus transmitted by arthropod vectors bites, mostly mosquitoes, and ticks. In Brazil, arbovirus is found in two families and two main genera of medical importance: Flaviviridae (Flavivirus) and Togaviridae (Alphavirus). The genre Flavivirus has many specimens of arbovirus and those that present greater relevance and clinical importance for public health are: Dengue (DENV), Zika (ZIKV), Yellow Fever (YFV), and West Nile Virus (WNV). Likewise, for the genre Alphavirus, the species of main relevance are Chikungunya (CHIKV) and the Mayaro (MAYV).

DENV is an urban arbovirus of greater relevance in the Americas, transmitted by female mosquitoes mainly of the species Aedes Albopictus and Aedes Aegypti, a daytime mosquito that multiplies in standing water deposits accumulated in backyards and inside houses, and has an etiologic agent with four distinct serotypes: DENV 1-4, and 18 genotypes (Brasil 2020c), meaning that it is possible to be infected four times, increasing the risk of developing severe dengue and likely to contract the hemorrhagic form.

WHO estimated that nearly 3200 million people worldwide had a high probability of catching the disease. Every year DENV infects around 390 million people, of which 96 million have clinical manifestations, and 20 thousand end up dead (Oliveira et al. 2019).

CHIKV first appeared in America in 2013, which caused an epidemic wave in many countries of Central America and Caribbean islands, and has three genotypes: West African, East-Central-South-African (ECSA), and Asian-Caribbean. In Brazil, until now the Asian lineage and ECSA were detected and now every state registers native transmission. CHIKV can also manifest an atypical or severe form and a high number of deaths are observed.

In the first half of 2015 another virus transmitted by Aedes Aegypti, ZIKV, was first identified in Northeast Brazil. After that, the virus spread in the Americas, except in Chile and Canada. Until now, there are known two virus genotypes: one African and another Asian (Brasil 2020c).

WNV is transmitted by Culex genus mosquitos and some wild bird specimens are natural WNV hosts that act as amplifying sources of mosquito infections. WNV has just one serotype but presents significant genetic variation and differs in at least seven genetic strains. However, strains 1 and 2 are the most widespread and are generally responsible for the majority of the epidemics found in Europe, Africa, the Middle East, the Americas, and Oceania.

Characterized by its epidemiological relevance, YFV is a Flavivirus responsible for frequent outbreaks registered during the historical national series, by clinical severity, with high lethality in severe forms associated with the expansion of viral circulation area in the last decades and also with the infestation by Aedes Aegypti and Aedes albopictus in Brazilian municipalities. At the end of 2016, there was a broad outbreak of YFV in Brazil, which reached large urban Brazilian centers and lasted until 2017 (Brasil 2020c).

The simultaneous circulation of DENV, CHIKV, ZIKV, and, on a smaller scale, also by YFV and WNV, in addition to another arbovirus, constitutes a great challenge for Brazilian health assistance and surveillance, including timely identification actions of suspected cases (the disease symptoms are very similar), clinical and laboratory diagnosis and in triggering control actions. (Brasil 2020c).

Since the urban arbovirus shares several similar symptoms with other diseases, there is an additional challenge to initial clinical detection, making it difficult to adopt adequate clinical management and, in this way, propitiating the increase in the occurrence of severe forms of the disease and, eventually, increasing the number of deaths (Fonseca et al. 2019).

### 6.2.2 Dengue fever

Disease found in tropical and sub-tropical climates (Viana & Ignotti 2013), mostly in urban and semi-urban areas with variations in risk influenced by city elevation (Watts et al. 2017) rainfall, temperature (Siraj et al. 2017), relative humidity, and unplanned urbanization (WHO 2020).

In 2012, an outbreak on the Madeira islands, Portugal, resulted in over 2000 cases. Mainland Portugal and 10 other countries in Europe detected imported cases and now autochthonous cases are observed on an almost annual basis in many European countries. Dengue is the second most diagnosed cause of fever after malaria among travelers returning from low and middle-income countries (WHO 2020).

In 2020, several countries reported increases in the number of cases: Bangladesh, Brazil, Cook Islands, Ecuador, India, Indonesia, Maldives, Mauritania, Mayotte (Fr), Nepal, Singapore, Sri Lanka, Sudan, Thailand, Timor-Leste, and Yemen. The occurrence of vector-based diseases is closely related to climate variations and thus to global warming. Hotter summers, higher humidity, and changes in precipitation regimes are expected with greater frequency and intensity and consequently with an increase in the geographical dispersion of vectors and the risk of these diseases (Khedun & Singh 2014).

Dengue prevention and control depend on effective vector control measures, and community involvement can improve vector control efforts substantially (WHO 2020). A vast majority of cases are asymptomatic or mild and self-managed, so the actual number of dengue cases are under-reported or are misdiagnosed as other febrile illnesses. There is no specific treatment for dengue and severe dengue, and the disease can rapidly evolve from a feverish state to more severe conditions. Among its complications are neurological and cardiorespiratory changes, liver failure, gastrointestinal bleeding, and pleural effusion. Severe dengue is a potentially fatal complication, due to plasma leaking, fluid accumulation, respiratory distress, severe bleeding, or organ impairment (WHO 2020).

In 2019, until the end of August, 1.544.987 probable cases were registered in Brazil (Brasil 2020c), far exceeding (7,5 X) the 2018 registered number of 205.791.

In 2020, until the 50th week, 979.764 probable cases were reported (466,2 cases / 100 thousand habitants). The distribution of cases by region was: Midwest (1.200 cases / 100 thousand); south (934,1 cases / 100 thousand), southeast (376,4 cases / 100 thousand), northeast (261,5 cases/ 100 thousand) and north (120,7 cases / 100 thousand). The number of probable cases, however, is probably underestimated due to COVID-19 presence with people avoiding going to the doctor (Brasil 2020a).

In 2022, until the 10th epidemiological week, 161.605 probable cases occurred in Brazil (incidence rate of 75.8/100 thousand). In comparison with 2021, there was an increase of 43.9% for the same period (Brasil 2022a).

The greatest dengue fever incidence areas coincide with developed states: São Paulo - SP (IDH=O,783; GINI=0,45), Goiás - GO (IDH=0,735; GINI=0,45) and Minas Gerais - MG (IDH=0,731; GINI=0,46), in Figure 6.1. Municipalities like São Caetano do Sul (IDH=0,862; GINI=0,360) and Assis (IDH=0,805; GINI=0,42) in SP present highs levels of dengue fever. Disease deaths in 2019, were 782 and the major lethality ratio (deaths/100 cases), occurred in the Midwest (0,08%) followed by the South region (0,06%), and the highest lethality is over 60 years old, especially over 80 years old, with greater relative risk when compared with the range of 1 to 4 years old.

Seasonal variation in temperature (Siraj et al. 2017) and rainfall influence the dynamics of the vector and the incidence seasonality of the disease (Viana & Ignotti 2013) that occurs in Brazil in the first half of the year when there is a higher incidence of cases. Figure 6.1 displays the main numbers.

### 6.2.3 Chikungunya

Chikungunya is a viral disease transmitted to humans by infected mosquitoes and it is caused by CHIKV. The disease shares some clinical signs with Dengue and Zika and can be misdiagnosed, and this is the reason why there is no real estimate for the annual number of people globally affected. Mostly, it occurs in Africa, Asia, and the Indian subcontinent, a major outbreak in 2015 affected several countries of the Americas, and sporadic outbreaks are seen elsewhere too (WHO 2020b).

The proximity of mosquito breeding sites to housing is a risk factor for Chikungunya, but deaths are very rare and almost always related to other existing health problems. There is currently no vaccine or specific drug against the virus, so the treatment is focused on relieving the symptoms (WHO 2020b). Lethality rates for those over 80 and under one-year-old are higher than for other groups, and during the 2018-2019 period, there were 76.742 (2018) and 110.627 (2019) recorded cases in Brazil (Brasil 2019).

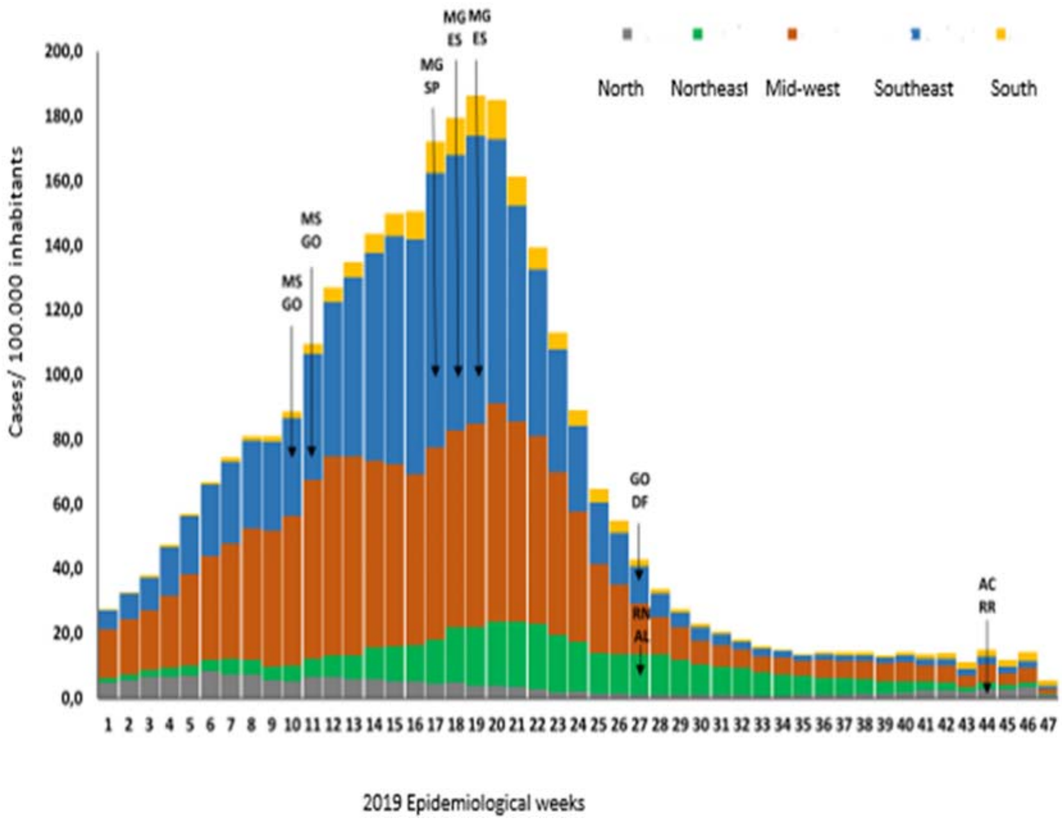


Figure 6.1 - Dengue incidence rate distribution by region in 2019 with predominance in the first half of the year (Brasil 2019).

Chikungunya caused, in 2019, in Brazil, 92 deaths, and the major ratios occurred in the Midwest region (0,09%), followed by the Southeast and Northeast (both with 0,07%), and concerning the Zika it was 3 deaths, by laboratory criteria, at Paraiba State.

In 2020, Brazil has reported 80.914 probable cases (38,5 cases/100 thousand inhabitants). The southeast and northeast regions present the highest incidence rates (102,2 cases/100 thousand) and (13,1 cases/100 thousand), respectively.

Until the 26th epidemiological week, 72,8 % of Chikungunya notifications occurred (58.884 probable cases), and the incidence rate was 28 cases/100 thousand inhabitants.

The states of Espírito Santo (ES), Bahia (BA) and Rio Grande do Norte (RN) stand out. Between the 27th and 50th epidemiological weeks (2020), 27,2% of Chikungunya's probable cases were reported (22.030 cases), an incidence rate of 10,5 cases/100 thousand inhabitants. During this period only the state of Sergipe (SE) presented an incidence rate above 100 cases/100 thousand inhabitants.

#### 6.2.4 Zika

Zika virus disease is caused by a virus transmitted primarily by Aedes mosquitoes, which bite during the day. Symptoms are generally mild and include fever, rash, conjunctivitis, muscle and joint pain, malaise, or headache and typically last for 2–7 days.

Most people with Zika virus infection do not develop symptoms. Zika virus infection during pregnancy can cause infants to be born with microcephaly and other congenital malformations, known as congenital Zika syndrome.

Infection with Zika virus is also associated with other pregnancy complications, including preterm birth and miscarriage. An increased risk of neurologic complications is associated with Zika virus infection in adults and children, including Guillain-Barre syndrome, neuropathy, and myelitis (WHO 2018).

Until August 2019, it registered 9.813 probable Zika cases in Brazil, well above 2018 (6.669 cases) and in 2020 (7.119 cases) until the 49th week (3.4 cases/100 thousand). Northeast presented the highest incidence rate (9.1 cases/100 thousand), Midwest (3.7 cases/100 thousand), and North (2.0 cases/100 thousand). The state of Bahia (BA) has 49.5% of Brazilian cases.

Important cases in pregnant women, by the effects (fetuses' microcephaly) with 1.649 probable cases were registered (447 confirmed). The distribution by states is according to the Online Notifiable Diseases Information System (Sinan-online 2019): RJ, 43% (192); ES, 15% (66); MG, 10% (47); Alagoas, 7% (32); Paraiba, 3% (16) e Mato Grosso do Sul, 3% (14).

An overview of the detection rates and spatial distribution in Brasil, in 2019, shows Dengue, Chikungunya, and Zika spreading (Brasil 2020c). However, due to the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-COV2) worldwide epidemic outbreak, all resources were directed to control the Coronavirus Disease 2019 (COVID-19) disease, restraining the battle against other types of diseases and viruses. There is an urgent need to make the shift, and promote resources to fight the urban arboviruses, especially in tropical regions and in areas where the Aedes Aegyptis mosquito has been frequent.

### 6.3 Methodology

In this section, we briefly describe all the variables used in this research, their sources, as well as all the steps performed to shed some light on their possible relationships. After the merging of all required datasets, we were able to include 4100 municipalities in the analysis, i.e., 73,6% of the 5570 Brazilian municipalities, covering 89% of the population. The analyses were implemented in R software, version 4.1.2 (R Core Team, 2022), using the R packages "Performance Analytics" (Peterson et al., 2020) and "Data Explorer" (Cui, 2020), and data were in dataset Mendeley repository (Novaes & Pinto, 2022) and in Annex A.

The literature confirms through systematic reviews on the epidemiological areas of interest, the associations of temperature and precipitation with dengue fever, and, similarly, to other Aedes Aegypti vector-borne diseases (Li et al. 2020). A few even focus on the analysis of those factors over a specific territory (e.g., for Brazil see Viana et al. 2013). Particular papers focus on non-climate/weather factors, such as the urbanization degree (Lowe 2021), but fail to provide a nationwide perspective. To account for those pitfalls, the variables used are described as follows:

- The Aedes variable is related to the Dengue fever, Chikungunya, and Zika disease cases, that occurred during the 2019-2021 period. The source is the Department of Informatics of the Unified Health System (DATASUS) dataset (Brasil 2022);
- The ac_sw variable considers urban roadways (km) without natural, or built, drainage systems. The source is the National Sanitation Information System (SNIS) (Brasil 2021c) dataset on urban drainage and stormwater management;
- The ac_ws variable covers water supply irregularity or total urban population at water risk, i.e., with a high probability of finding themselves with poor or nonexistent water supply. The source is the Nationwide Water Security Index Dataset (Brasil 2020b);
- The ac_ww variable includes the urban population without wastewater services. The source is the SNIS wastewater services dataset (Brasil 2021a);
- The idhm variable is the municipal human development index, a statistic composite index of life expectancy, education, and per capita income indicators. The source is the continuous national sample survey of households 2020, which updates the census dataset (Brasil 2021);
- The Gini variable is the Gini index, which is a measure of statistical dispersion that highlights income or wealth inequalities within the population. The source is the continuous national sample survey of households 2020, which updates the census dataset (Brasil 2021);
- The pib_cap variable is the gross domestic product (GDP) per capita of each municipality. The source is the local GDP dataset 2010-2019 (Brasil 2020).

The water supply irregularity data is considered without specifying how many hours or days events occur. Besides that, different areas of the municipalities show specific degrees of irregularity according to their different physical and socio-economic characteristics (Diniz 2019). Irregularity are factors that can accentuate inequalities within municipalities, and diseases are often identified with location within cities. However, water supply irregularity is the main factor that leads to higher health risk, i.e., the population at risk of poor or non-existent water supply (Brasil 2020b).

Finally, since Aedes Aegypti vector-based diseases are localized, they are difficult to analyze under aggregated data. Thus, to assess the previous variables across comparable territories, we split the data into climatic zones according to Köppen's climate classification (Alvares et al. 2013) and urban population density. In the last parameter, municipalities were categorized as having a lower or higher urban population density depending on whether they had until 2000 hab/km2 or more, respectively. Those 18 groups had the number of municipalities outlined in Table 6.2.

Table 6.2 - Brazilian municipalities grouped according to their climate and urban population density characteristics.

| Climate | Description | Population density | Municipalities |
|---|---|---|---|
| Af | Tropical rainforest climate | Lower | 94 |
| Af | Tropical rainforest climate | Higher | 40 |
| Am | Tropical monsoon climate | Lower | 198 |
| Am | Tropical monsoon climate | Higher | 62 |
| As | Tropical dry savanna climate | Lower | 400 |
| As | Tropical dry savanna climate | Higher | 125 |
| Aw | Tropical savanna, wet | Lower | 716 |
| Aw | Tropical savanna, wet | Higher | 219 |
| BSh | Hot semi-arid (steppe) climate | Lower | 225 |
| BSh | Hot semi-arid (steppe) climate | Higher | 46 |
| Cfa | Humid subtropical climate | lower | 855 |
| Cfa | Humid subtropical climate | higher | 147 |
| Cfb | Temperate oceanic climate | lower | 311 |
| Cfb | Temperate oceanic climate | higher. | 39 |
| Cwa | Monsoon-influenced humid subtropical climate | lower | 243 |
| Cwa | Monsoon-influenced humid subtropical climate | higher | 84 |
| Cwb | Subtropical highland or temperate oceanic climate with dry winters | lower | 227 |
| Cwb | Subtropical highland or temperate oceanic climate with dry winters | higher | 69 |
| | | **TOTAL** | **4100** |

## 6.4 Results and discussion

The results achieved can be analyzed by considering: first, the nationwide correlation matrix in figure 6.2; and second, the correlation maps (Figure 6.3) for each cluster of Table 6.2. The nationwide correlation matrix provided the results outlined in Figure 6.2. In figure 6.2, on the upper side of the diagonal, using the R package “Performance Analytics”, we present the pairwise correlation values, with p-values significance levels analyzed, ($p < 0.001$ it is represented by ***, $p < 0.01$ it is represented by ** and $p < 0.05$ it is represented by *). On the lower side of the diagonal, we display the bivariate scatter plots with a fitted line.

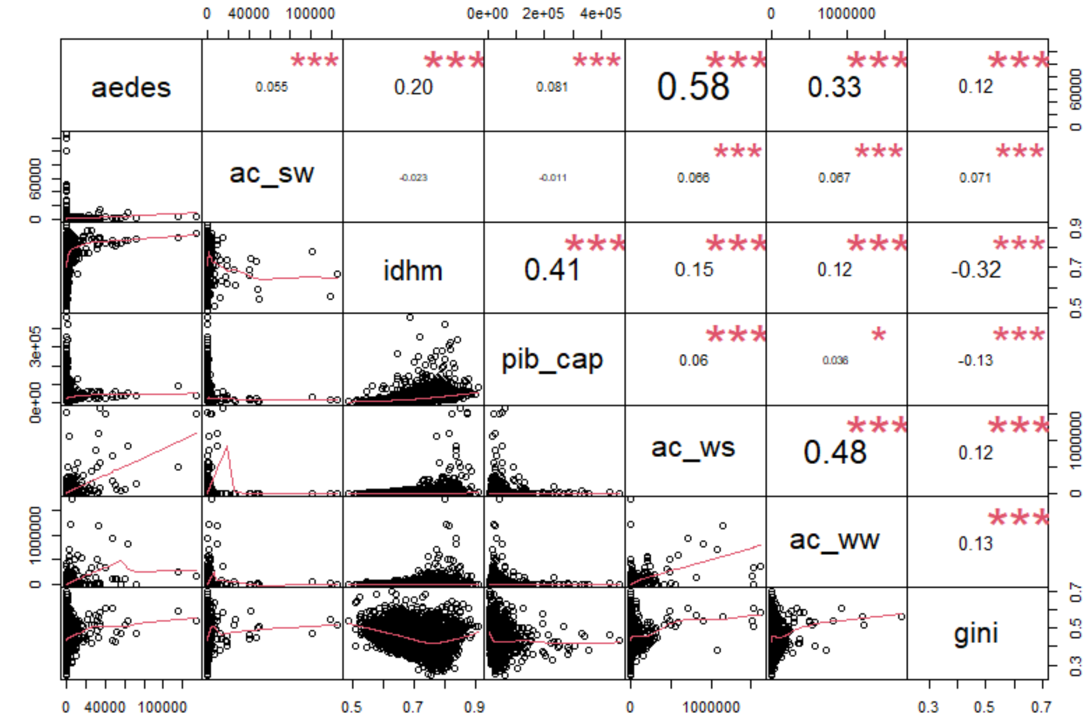


Figure 6.2 - Correlation matrix of all variables for 4100 Brazilian municipalities.

The overall results point to a strong correlation between the number of cases (var. Aedes) and the water supply (var. ac_ws) and wastewater services (var. ac_ww) variables, respectively corr. = 0,58 and corr. = 0,33. However, when we disaggregate the data, we find interesting results. In Figure 6.3, we highlight the results for each pairwise comparison with the number of cases (var. Aedes). In this figure 6.3, we labeled the municipalities with an urban population higher than 1 million.

The first conclusion reached, however, is that in the municipalities with high population densities, there is a positive correlation between idhm and the number of disease cases, or the bigger the idhm the greater the number of cases for three climates (Figure 6.3b): Am (0,52), Af (0,53), and As (0,57).

The correlation between the number of disease cases and the water supply irregularity or total urban population at risk, with poor or nonexistent water supply services, also for the municipalities with a high population density, the correlation is stronger with more climates (Figure 6.3d): Am (0,68), Af (0,93), As (0,93), Bsh (0,55), Cwb (0,95), and Cfb (0,71).

The correlation, for the municipalities with high population densities, between the urban road (km) without natural, or built, drainage systems are, for all the studied climates (Figure 6.3a): Am (0,73), Af (0,85), Aw (0,75), As (0,75), Bsh (0,58), Cwb (0,93), Cfa (0,65), Cwa (0,58), and Cfb (0,99).

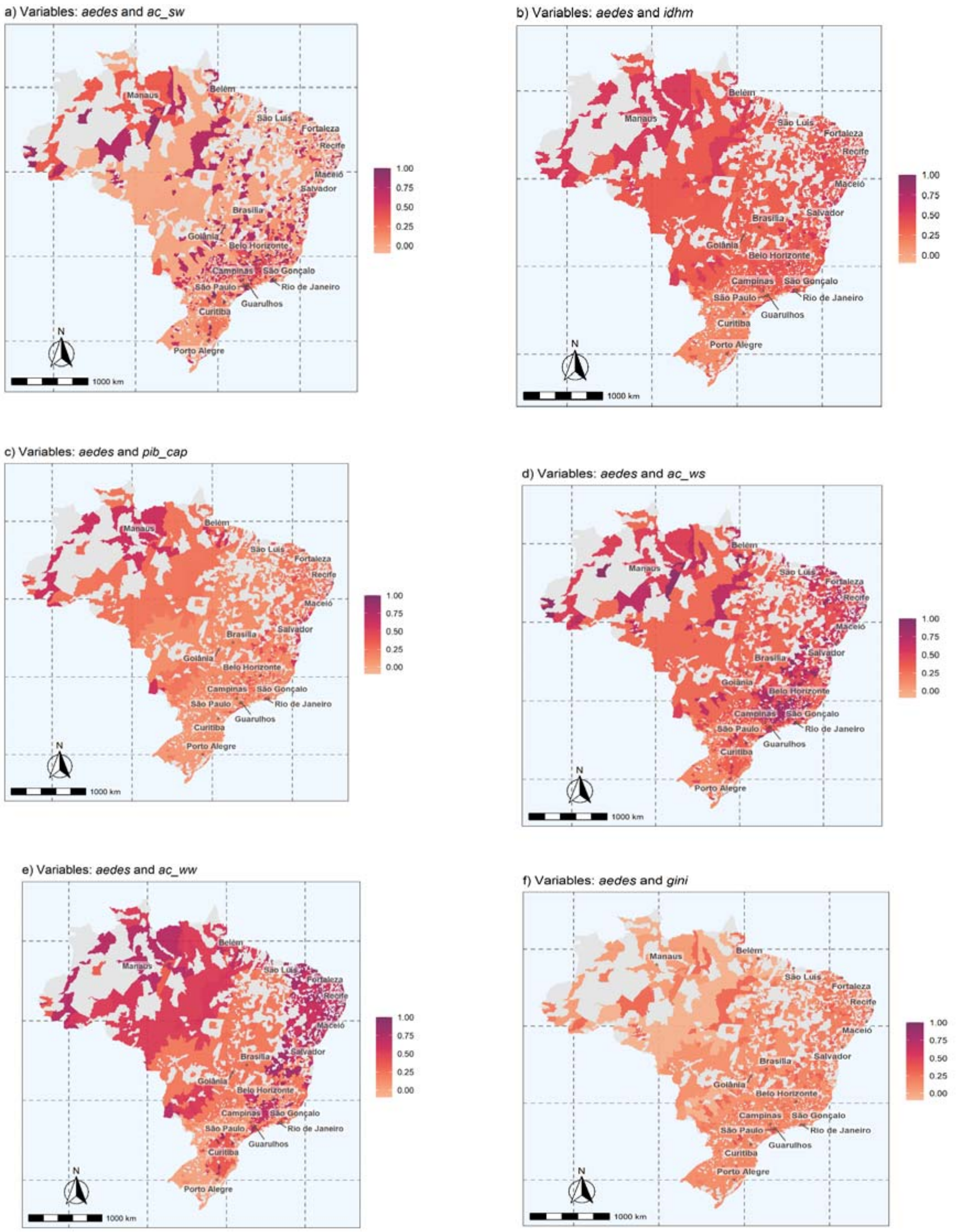


Figure 6.3 - Correlation maps of all Aedes pairwise comparisons for the 18 clustered territories.

Several Brazilian municipalities with water supply services have direct or indirect municipal management structures (55%) and in the remaining (45%) there is no municipal structure to manage stormwater management services (IBGE Munic 2017). Furthermore, municipal councils of WSS and healthcare are far from the degree of deliberative effectiveness desired, with lower social participation than expected and promoted by each sector legislation (Souza & Heller 2019).

An interesting case, is the situation of RJ, with significantly lower cases in recent years, which may be explained by a resilient effect due: to an increase in knowledge about the disease and mosquitoes breeding sites, improved health, and sanitary government teams responsible for fighting and prevention initiatives. Some studies highlight that there may be a natural time/territorial displacement (Xavier et al. 2017), e.g., in 2019, between March and June, there were 30 thousand disease cases and in 2020, in the same period, little incidence with just 216 disease cases. The lower number of 2020 disease cases, however, can be in part attributed to the greater presence of people at home due to the COVID-19 pandemic, which promoted great care in their home environments (G1. Globo 2020).

The case of the São Paulo water utility company (SABESP) is another interesting one. During the pandemic in SP (São Paulo's government electronic portal, in Portuguese Portal do Governo de SP 2020), SABESP provided free domestic water reservoirs to the most vulnerable, in partnership with private enterprises. This initiative can be followed and incorporated into public policy, which may allow extending its scope to rainwater reservoirs, as a large urban stormwater management experience, with the inclusion of vulnerable people.

There are, however, several contradictory aspects of the coexistence of dengue, COVID-19, and measures such as lockdowns and social distancing (Brady & Wilder-Smith 2021). While social isolation in 2020 has led to a reduction of dengue in some countries like Brazil and Colombia, in several others like Paraguay, Bolivia, French Guiana, and Suriname, there were increased outbreaks. It is expected that in places where surveillance and measures to combat the mosquito have been reduced, the presence of the vector will increase and consequently the related diseases. The reduction in dengue-related activities may have led to underreporting and the similarities in various symptoms contributed to confusing diagnoses, deaths, and notifications.

## 6.5 Conclusions

The presence of the Aedes Aegypti vector in cities is closely linked to WSS, e.g., due to water storage elements, either man-made or natural ones. We sought to analyze the population under a high water supply risk, which may lead to the use of temporary storage, either from rainwater or supplied water. Afterward, we assessed the existence of drainage elements in public urban roadways, highlighting the existence (or not) of stormwater infrastructures, which may allow the presence of puddles, i.e., breeding grounds for the Aedes Aegypti mosquito. Similarly, municipalities with a higher amount of urban population without wastewater services often imply a comparable deficit in terms of drainage infrastructure, allowing to shed some light on the impact of faulty drainage services in Aedes vector-based diseases. Additionally, the GDP per capita, the human development index, and the Gini index were verified, to try to relate the already known poor income distribution and inequalities with the study findings. Indeed, the results achieved do not imply causality, but rather guide a probable incidence.

In most variables, as the WSS status quo, a proxy is used to indirectly question the assumptions initially made. Service quality aspects are important, like irregular water supply or rainwater use, which require standardizations to enable the implementation of alternative ways toward WSS universalization, overcoming the persisting issue of incomplete urban infrastructures. From this point of view, the SABESP initiative, also triggered by the presence of COVID-19, of providing water tanks for free, with the participation of private companies (TIGRE and AMANCO) provides a possible solution. Even if the installation costs are borne by the customers, it seems an interesting public policy, not only to combat dengue and other diseases but to increase access to WSS.

Preventing future epidemics should be the way forward. The development of vaccines is a complex and time-consuming issue to be solved through research, that should be integrated with health and WSS policies, allowing to save resources and efforts. By building and managing more effective infrastructure, there is a reduced proliferation chance of mosquitoes, viruses, and diseases. Despite possible limitations, the strategic integration of prevention and vaccination resources, while adjusting the benefit-cost ratio, should bring greater welfare.

The absence of data related to urban stormwater management in the official (audited) databases is a limiting issue, and indicative of the lack of institutionalization of the subject in municipal, state, and federal structures, including the issue of permanent resources. Indeed, it is fundamental to the formalization of those databases, as the SNIS-stormwater (SNIS-AP), in a disaggregated way, of drainage and stormwater management data, such as, for example, the incompleteness of data regarding urban infrastructures in several territories. The lack of disaggregated data by neighborhood and income brackets, instead of states and municipalities, prevents the detailed identification of places with irregular water supply, absence of reservoirs, lower network pressures, the prevalence of the mosquito, and the disease. This constraint is also an issue for policy making. Thus, to improve the quality of the results achieved, there is a need to increase data collection activities throughout most Brazilian municipalities.

# 7. STORMWATER UTILITIES: A SUSTAINABLE ANSWER TO MANY QUESTIONS

This chapter was published in the Journal Sustainability, 2022, 14(10), 6179.
https://doi.org/10.3390/su14106179

## 7.1 Introduction

The management of urban stormwater has evolved with the understanding of its role and the good and bad characteristics that such water can bring to society. In each era, water has had different roles, but has always been connected with human activities, and cities were born and developed in close relationship with water. The close presence of water, whether for agriculture, energy production, navigation, or consumption, in most cases brought value to the territories, with the exception of urban flooding (See et al. 2020).

Cities continues to grow and man thought wastewater and stormwater were reasons for diseases, and that it was necessary to take it as soon as possible to rivers, lakes, estuaries and the sea. The function of the receiving water bodies was not only transport, but effluent discharge, without treatment, as is still the case in many places today. In the era of 'tout à l'égout' (Pinheiro 2019), the hygienist phase of the 19th century, the reigning order indicated was to move waste and rainwater away from the cities as quickly as possible, not only to avoid the proliferation of diseases, but also to prevent flooding. The concern was fundamentally hydraulic, with a focus on quantities and mass flows, i.e., the problem was reduced to the sizing of pipes and channels, a matter for engineers. Concerning stormwater drainage, there was an understanding that these were of good quality and free of pollutants (Imhoff & Imhoff 1985), reinforcing the idea that only volumes, mass flows, and dilution should be addressed. As for quality, represented by pollution, people said that it was only a matter of diluting polluted volumes into larger volumes, free of pollutants. The issue of sizing structures for drainage and dilution went through the discovery of which rains could be predictable in each region, a problem of hydrology and statistics, the latter helping by informing the probability of occurrence of certain volumes and the associated risks, expressed by determining the so-called return times of the events. Again, problems and issues are more related to engineers. From the possession of this information, the problem of the decision to choose return periods, or "project rainfall", depended on political decisions, closely linked to investments to be made in physical infrastructure and their respective risks.

With the advances brought by microbiology and epidemiology and Koch's discoveries regarding cholera, the understanding grew that the issue of wastewater quality was of crucial importance allowing sanitary approaches to sanitation and drainage to occupy a prominent place; it was the beginning of the sanitarian phase after the hygienist phase of the 19th century. The first wastewater treatment plants started to be developed at the turn of the century (Monte et al. 2016).

The decision about the type of treatment and size of the facilities involved the determination of the desired quality levels for effluents, an issue that no longer affected only engineers, but also health professionals, considering the risks that society would be willing to undergo and the alternatives of investments to be made, i.e., again decisions of political nature.

Currently, as of the nineties, there is an upsurge in urban flooding problems, for several reasons, with two of them more relevant and interconnected: demographic growth, with the consequent territorial expansion of the urban fabric, and climate change, leading to the perception that just draining downstream, ever further and with greater volumes, treating rainwater effluents in a concentrated manner, at the point of discharge ("end of pipe"), in a vision on the one hand hydraulic and on the other hygienist, did not even find physical spaces for the task (Tucci & Meller 2007).

Later on, simultaneously with the environmental and right to the city movements, the vision of sustainability took over urban environments that started to understand water not as a problem anymore, but as a solution to old and new issues of quantity and quality, such as scarcity, well-being and comfort exemplified, respectively, by its use in daily life, embellishment and the fight against "heat islands" (Bertrand-Krajewski 2013).

According to this approach, alternative techniques emerge, in opposition to the traditional method of removal, which mainly uses buried pipes. The new mentality is one of harmonious coexistence with water; therefore, in addition to its visible presence on the surface, there must be treated at the source, that is, as close as possible to the places of origin, where precipitation occurs (Hamel et al. 2013).

In terms of management, what worked before, the centralized management with command and control, concentrated in the public power, requires changes, and a change in the traditional management paradigm. With new and multiple actors assuming different roles, disputing and sharing the resource represented by urban stormwater, practices are gradually changing and favoring the decentralization and democratization of decisions (Novaes & Marques 2022).

At the same time, the change reaches aspects of service funding, as the understanding had always been that flooding issues, linked to large volumes and flows (hydraulics), were usually borne, at great expense, by general (centralized) public budgets. The feasibility of solutions at the source, or located where precipitation occurs, generally requires potentially lower and decentralized expenditures enabling private sharing and participation in the solution in distributed manner (Braden & Ando 2011).

Around the world, this paradigm shift is being studied to create the best format for financing and management. The USA and Canada, countries where there have been successful experiences for some time, around three decades (Black & Veatch 2018), materialized through stormwater programs, are partially or totally based on the collection of tariffs from users. Users became

important and stable sources of funds, specifically for the improvement of urban stormwater management systems to comply with legislation. In the USA and Canada, the collection mechanisms for funding the activity are called Stormwater Utilities (SWUs), with specific characteristics in each place, but which deserve to be observed in order to learn from them.

The contributions of this chapter lie in the approach to a subject absent from the literature, despite its importance, exemplified by the number of existing cases and the importance of the countries in which it is presented. Despite this, however, SWUs are financing and management mechanisms for urban stormwater management services that are little used in most countries where funding is required. In this sense, the contribution is to expand the dissemination and discussions around the subject and its application, so that through its knowledge its use can be expanded and the improvement of stormwater management can be achieved.

Besides this short introduction, the chapter is structured in more four sections. The second section will focus on issues related to the origin and reason for the emergence of SWUs. In the third section, several cases where SWUs exist are presented; in the fourth section the results and discussions are briefly presented; and finally, in section five, the conclusions are drawn. Figure 7.1 presents a flow chart of the study with each chapter, its main aspects, as well as some of its interconnections.

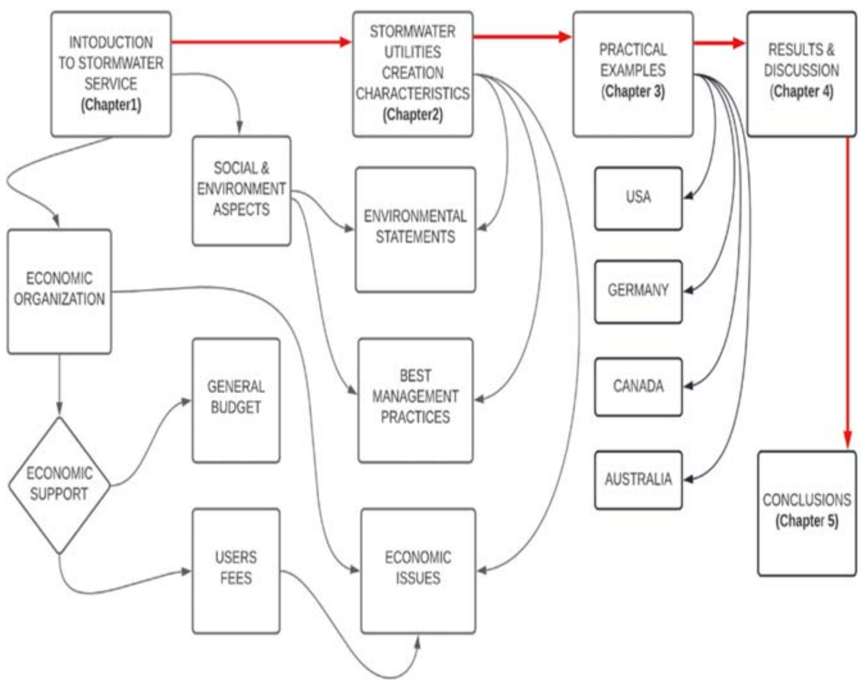


Figure 7.1 - Study flow chart.

## 7.2 The creation of SWUs

In line with the diversity of aspects to be addressed, new demands for resources and management have arisen from the entry into force of legislation and regulations targeted at improving the quality of urban service delivery systems, including stormwater management. Costs expected to result from climate change (increased frequency, intensity, and duration of rainfall with flooding and rising sea levels) have led to a search for alternatives to system funding through the application of the user-pays principle, based on charges levied on users according to their contribution to runoff, supporting, even if sometimes only partially, the new costs to be assimilated by budgets (Veiga et al. 2021). In each location, these financing methods, often associated with new management practices, have become institutionalized and have been given different names: SWU, stormwater fee, stormwater user fee, and stormwater service fee (Kea et al. 2016).

Cities support increasing costs, but with no proportionally crescent budgets, of maintenance and replacement of ageing infrastructure, of the new built areas and of quality and quantity costs occurring depending on the climate changes. In Canada, due to climate changes, the stormwater infrastructure is considered in critical conditions, but it was built in the last twenty years. With estimated lifetime of 70-100 years for linear systems, 50-80 years for structures and 25 years for electrical and mechanical components, these picture is surprising (Association 2019).

The SWUs, mechanisms to obtain resources for financing urban stormwater management, resulted from the perception by the American municipalities of the need to find economic means to cope with the increasing pressure on their budgets to meet socio-economic and environmental demands. These demands, were incorporated into the American legislation through water quality control requirements due to diffuse urban stormwater pollution, considered a pollution point source at the point of discharge.

The legal and regulatory framework, developed over the last five decades, since 1972, with the Clean Water Act (CWA) aimed at controlling water quality, revised in 1987 through the Water Quality Act (WQA) with provisions added for five categories of stormwater discharge. These provisions, classified under Phase I, established a set of restrictions for large and medium-sized municipal storm sewer separator systems (MS4). These systems cover populations greater than 100,000 and according to discharge quality permits, bring them into compliance with the National Pollutant Discharge Elimination System (NPDES). In 1990, the final rules were established for Phase I, and later, in 1999, for Phase II. In small MS4, in addition to systems for less than 100,000 inhabitants, there are industries and construction areas of 4,047 to 20,234 m² (1-5 acres). Stormwater eventually carries pollutants such as nutrients, pathogens, sediment and metals, but must fall within the limits of the Total Maximum Daily Load (TMDL), a pollutant load that can be discharged to a given receiving body, without failing to meet the quality standards established by the States. The TMDL program applies to all MS4 systems, industrial and construction activities, and its limits include both point source and diffuse source loads (NACWA 2018).

Additionally, from the 1980s onwards, partly as a reflection of the taxpayer revolts of the 1970s, and the passage in 1978 of proposition 13 in California, which placed limits on property taxation, some governments began to consider tariffs as a better source of resources than taxation for urban services. Thus, more favorable conditions were created for the introduction of stormwater utilities, a period considered as the utility model different from the traditional tax-supported public works model until, then predominant (Grigg 2013).

The creation of SWUs in USA is not mandatory, depends on the perception of their need by the populations, policymakers and those in charge of state legislations, on which SWUs depend to be implemented. There is no pre-defined size, with small communities such as

Indian Creek Village in Florida (only 88 people), according to the 2010 Census population and Los Angeles (over 4 million inhabitants).

There are nine models for calculating collection rates: dual, flat, tier, square foot, parcel acre, meter, usage, equivalent residential unit (ERU), and residential equivalent factor (REF). Some are based on impervious areas, such as the most widely used, ERU. Others are based on runoff generated, such as REF, or other forms of measurement. ERU is more popular in places with high population density and high property values while flat fee is more popular in places with low population densities and low property values (Kea et al. 2016).

Thus, in the absence of a general rule, the junction of necessity and opportunity has favored the creation of SWUs. The opportunity often occurred after catastrophic events, such as hurricanes Katrina, in Louisiana (LA) and Mississippi (MS), fifteen years ago, and Sandy, in Connecticut (CT), New Jersey (NJ) and New York (NY), eight years ago, after which, however, by 2021, there were still no SWUs in place.

In the USA, the coming into force of legislation showed relationship with the higher number of deployed SWUs (Kea et al. 2016), as also a clear definition of the legal authority in charge of each city, county and watershed. In some way, important was the key role played by the professional organizations, providing information, support and encouragement to communities interested in the implementation of SWUs.

## 7.3 Stormwater Utilities (SWUs)

### 7.3.1 USA

In the US, according to research by the University of Kentucky, there are 1851 distributed SWUs identified, in 41 states and the District of Columbia (Campbell & Bradshaw 2021). While the number of SWUs may seem large, it becomes small when compared to the number of 22,389 communities computed as participants in the National Flood Insurance Program (NFIP), as of June 2019, meaning there are SWUs in less than 10% of this total. Despite a long history of SWU implementation in the US, the main challenges that remain for communities, regardless of their size, are related to adequacy of funding and public support, which are compounded by aging infrastructure (Black & Veatch 2021).

The national average monthly fee paid by single-family homes is US$5.94, increasing over time according to the consumer price index (CPI), with values varying from zero to US$45, although there are situations where reductions may occur and the range may reflect stormwater needs and also political contexts. The most widely used calculation method is based on the impervious areas of the land and is based on the ERU system, an average of the single-family residential impervious areas of land, but in some communities, a value can be defined based on the average of all the areas of residential land. The method calculates the amount to be charged based on the impervious areas of the lots, regardless of the total areas. The ERU is calculated through sampling carried out through field research (Montenegro 2017), but can also be estimated through aerial or satellite images. Once the total impervious area of residential properties (AI) is obtained, it is divided by the number of properties, giving the ERU value (Campbell, & Bradshaw 2021).

For non-residential land, the rates are proportional to the ratio of the impervious area of the land to the ERU. The most commonly found average size for ERUs (895 utilities) in the University of Kentucky survey was 3072 squares feet of impervious area, so it is important to determine ERUs accurately so that no one pays a disproportionate amount. There are other taxation systems, such as tiered systems (254 utilities) or flat fees (230 utilities). The ERU can be considered a system of infinite levels or steps and the flat fee and dual fee (108 utilities) as systems of a single level or step, the latter considering taxation for residences and another one for non-residential properties.

An example, taken from research conducted in 2021 by the University of Kentucky (Campbell, & Bradshaw 2021), illustrates calculation systematics for a hypothetical area and allows conclusions to be drawn: residential waterproofed area = 15 x 107sq ft; non-residential waterproofed area = 15 x 107sq ft; ascertained ERU = 3,000 sq ft; annual amount required for the selected level of service = $12 million and every household pays a fee of 1ERU.

Dividing the total waterproofed area (30 x 107 sq ft) by the standard computed ERU gives a number of 100,000 ERUs, 50% of which are residential areas and 50% of which are non-residential areas, and therefore a monthly fee of $1 million is required, which divided by the number of 100,000 ERUs indicates a base amount of $10 per ERU per month.

If, however, for example for political reasons, it is decided that the assessed value to be used for non-residential areas should be for standard ERUs with 4000 sq ft and not 3,000 sq ft, the number of non-residential ERUs becomes no longer 50,000 but 37,500 (1.5 x 107 sq ft divided by 4000 sq ft), totaling no longer 100,000 but 87,500 ERUs in the municipality (50,000 residential and 37,00 non-residential), which implies a value no longer of $10/ERU, but of $11.43 per ERU (87,500 x 11.43 = $1million per month) and, according to the following equations 7.1 and 7.2, the percentage of costs will no longer be 50% between residential and non-residential areas, but 57% for residential and 43% for non-residential.

$$Frac_{res} = ERU_{res} / ERUs_{res} + IA_{nonres} / ERU\ used \quad \text{(Equation 7.1.)}$$

$$Frac_{nonres} = 1 – Frac_{res} \quad \text{(Equation 7.2.)}$$

Where:

$Frac_{res}$ corresponds to the fraction of the stormwater program paid by residential customers; $ERU_{res}$ is the total number of residential ERUs in the city; $IA_{nonres}$ is related to the total non-residential impervious area in town; ERU used is the actual ERU used as opposed to the true ERU.

Similarly, if we use the standard ERU in the non-residential area with the value of 2000 sq ft, we will obtain 125,000 ERUs (50,000 residential and 75,000 non-residential) whereby the value of the ERU equals USD$8 (125,000 x 8 = 1million) with the residential area bearing 40% and the non-residential area bearing 60% of the costs. Similarly, for ERU=1000 sq ft, the percentages of monthly costs borne become 25% for residential areas and 75% for non-residential areas or, for ERU=5000 sq ft, 62.5% for residential and 37.5% for non-residential users respectively, according to equations 1 and 2. From this, it is clear that the determination of the ERU is a very important aspect to have a fair taxation system that reduces the possibility of questioning.

Still, as to the example, it should be highlighted that it does not take into account possible reductions, applied in some municipalities, due to the placement of rainfall retention devices on lots or even the disconnection from collective drainage systems, besides other aspects that motivate exemptions.

The second most popular model is the REF method, with 133 utility cases, this system is based on the amount of runoff from a unit compared to the amount of runoff by a standard property of a single-family dwelling, considering an event with a determined return time, for example, 2 years and 24 hours of rain, calculated by the rational method or the Soil Conservation Service (SCS). Besides relying on hydrological information over time and soils, this system penalizes commercial properties for shorter return times and residential properties for large return times (Campbell et al. 2016).

Thus, building a model for calculating fair taxation, making SWUs accepted by all as a development factor, is still a complex and evolving task that depends on several parameters in addition to policy options in each location and different development context. Nevertheless, some SWUs have made significant capital investments through user fee programs, such as, for example, in Fort Collins (USD$120 million), Bremerton (USD$55 million), and Raleigh (USD$100 million), initiated in 1980, 1994, and 2004, respectively, and in the second case the investment is to promote the separation of the existing unitary system (Black & Veatch 2021).

In 2021, most of the 73 participants in the survey, which covered 20 American states, conducted by the consulting firm Black & Veatch, declared to have: a separating system (82%); a municipality as their area of jurisdiction (97%); carry out the collection of drainage fees on water and sewerage bills (78%); consider a drainage website the most effective means of ensuring approval and support for the fees charged to users; and to fit into Phase II (population under 100,000 population) of the EPA's Municipal Separate Storm Sewer Systems (MS4s) discharge regulation program.

EPA has 855 participants in Phase I MS4s (population over 100,000) and 6695 in Phase II MS4s which includes many cities and regions. In the majority, i.e., in 54% of those locations, where combined systems still exist, the combined systems account for less than 25% of the total system. Despite being the third most important item cited in the survey and that 73% of systems have, according to the survey, aging drainage infrastructure, asset management plans are in place in only 63% of systems falling under MS4s Phase I and 35% falling under MS4s Phase II.

The main percentages of instruments used for funding corresponds to cash (78%) or debts (22%), according to the percentages of answers for each type of instrument. As for the main sources of revenue, 95% of the answers indicate that more than 75% of the amounts are supported by fees received from users and the three main activities described as included in the O&M budget are: illicit discharge detection and elimination (96%), best management practices (90-92%) and public education (92%) [16].

Table 7.1 - Instruments and percentages of funding (Brodnik et al. 2017).

| ***Majority Financed*** | | ***Majority Cash Financed*** | |
|---|---|---|---|
| ***General obligation bonds*** | *18%* | *Stormwater user fees* | *84%* |
| ***Wastewater / stormwater revenue bonds*** | *11%* | *Grants* | *26%* |
| ***Other debt*** | *8%* | *Other cash* | *8%* |
| ***mbined stormwater / other bonds*** | *5%* | *Permitting and other fees* | *7%* |
| ***Sales tax bonds*** | *0%* | *New development impact fees* | *7%* |
| ***Benefit district bonds*** | *0%* | *Ad valorem taxes* | *3%* |
| | | *Sales taxes* | *1%* |
| | | *Special assessment districts* | *1%* |

Table 7.2 - Sources of revenue (Black & Veatch 2021).

| | **Stormwater user fees** | **Stormwater impact fees** | **Miscellaneous stormwater fees** | **Taxes** | **Grants** | **Other** |
|---|---|---|---|---|---|---|
| Over 75% | 95% | 0% | 0% | 25% | 0% | 15% |
| 50%-75% | 3% | 0% | 0% | 0% | 0% | 0% |
| 25%-50% | 1% | 8% | 8% | 25% | 0% | 0% |
| Less 25% | 1% | 92% | 92% | 50% | 100% | 85% |

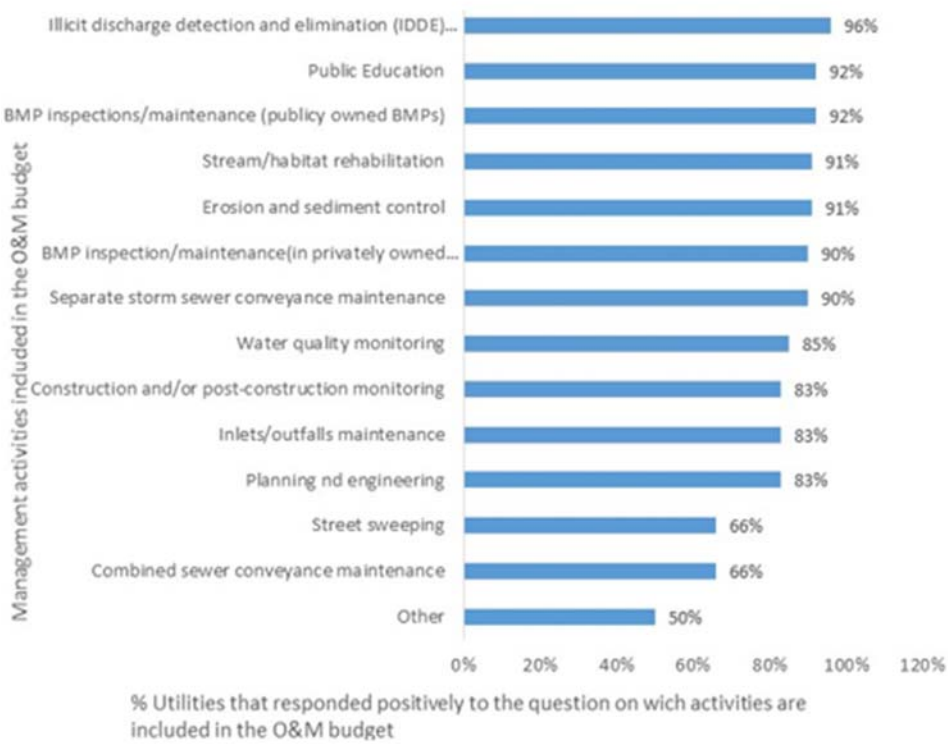


Figure 7.2 - Management activities included in the annual operation and maintenance budget (Black and Veatch. 2021).

### 7.3.2 Germany

In Germany in several cities since the 1990s, based on the polluter pays principle, stormwater management charges have been introduced taking into account the impervious area. Since many cities have single systems, i.e., systems that deal with both stormwater and wastewater systems, they are charged jointly through a single fee and the calculation is based on water supply consumption, which is not a fair way of charging. From the idea of changing to a fairer system, based on the mentioned principle, in most states the fee for impervious areas was introduced, but just a value around only 20-75% of the costs of stormwater and wastewater management (Vietz et al. 2018).

There are two ways to calculate the impervious area: by estimation, according to zoning (Munich since 1970), or by measurement (Hamburg- since 2012, Dresden - since 1998, and the State of Baden-Wuerttemberg - since 2010). Calculation by estimation is easier to implement but more inaccurate. The implementation of the levy resulted in waterproofing area reductions of 4.5M m² or 240,000m²/year in Munich with 3,000 ML groundwater recharge; 10% reduction of waterproofing area per person in Dresden; and in the state of Baden-Wuerttemberg, 48% of the cities reported decreases, 11% with high reductions already in the first two years after the levy implementation.

In Munich, maps with colors identify the runoff coefficients, being 0.9 for the blue zone, in the city center; 0.6 for the pink strips, in intermediate regions, between the center and the outskirts; 0.5 for the outer suburban areas (orange); and 0.35 for residential plots in the outer suburbs (green) (Vietz et al. 2018). Additionally, several beneficial effects were noted, such as the reduction of the quantities treated in the combined systems in Munich and Dresden, enabling process optimization and deferring infrastructure upgrades of existing systems (Vietz et al. 2018).

### 7.3.3 Canada

In Canada, only 4 out of 48 utilities use the ERU system and eight use property value or "ad valorem" taxation and the average taxation is CD$10.67 (Campbell & Bradshaw 2021).

In the Victoria Community, located in British Columbia, integration between Stormwater Management (SWM) and street sweeping has recently been discussed with the latter usually being included in property-related fees (Tasca et al. 2017).

In Victoria, stormwater bills are issued annually to property owners and are determined based on property-specific characteristics such as impervious areas (roofs, car parks, and driveways) measured with the aid of building plans, aerial photography and mapping using georeferencing technology (GIS). The value, in 2022, is of CD$0.654 per square meter and street cleaning is determined by frontage length and street type, charged per meter of lot frontage, varying according to table 7.3 below.

The property impact on stormwater system through a flat portion of the charge, based on the building code is: Low Density Residential - CD$0; Multi-family Residential - CD$81.79; Civic / Institutional - CD$72.98 and Commercial / Industrial - CD$148.38. Finally, there is a program in which property can be registered if they have ten or more parking spaces and are self-businesses, recreational facilities, recycling operations, storage yards, or have construction activities on site, paying CD$169.70 per year (2022).

Table 7.3 - Victoria charge, according to the type of street.

| Street type | CD$/ meter of street frontage |
|---|---|
| Local streets | 1.81 |
| Collector streets | 3.84 |
| Arterial streets | 4.35 |
| Downtown streets | 43.60 |

In a study conducted in the City of Thunder Bay comparing the various forms of taxation for stormwater funding, the conclusions were that urban properties subsidize rural areas by approximately CD$300.00 annually and that residential properties account for 67% of the contributions to the stormwater program while non-residential properties get the remaining 33%. However, the runoff from residential areas is only 58% and the remaining 42% comes from non-residential areas, meaning that a distribution based on contributing areas would lead to a 9% redistribution, i.e., the average residential properties would bear 9% less while the non-residential areas would bear an average 9% more in levies. Although this distribution would be fairer, one of the recommendations of the study was that only above 10% would the change be worthwhile, given the high implementation costs of reallocating only CD$360,000 per year from residential to non-residential plots, against a budget of CD$4M and minimal apportionment of the difference among the 38,203 existing residential properties. There are, however, other aspects that should be considered in the long term, such as the observation that property tax encourages sprawl while the user fee option encourages densification, and other issues including environmental liabilities (AECOM 2020).

### 7.3.4 Stormwater management in Australia

The changes that occurred in water management in Australia over the past five decades determined its current state, according to a path dependence viewpoint (Otoch et al. 2019).

However, according to Brown and other scholars, moments of tension and alignment existed between six distinct institutional logics (decision making, risk, sustainability, water quality, infrastructure, and demand) that coexisted in permanent evolution. Thus, according to a study conducted in the period between 1970 and 2015, throughout all the time, the urban water management sector in Australia showed great complexity (Brodnik et al. 2017).

In this context, the evolution (rather than a revolution) towards the current practices of Sustainable Urban Water Management - SUWM, which emerged in the 1990s, was based on the trajectory traveled by the logic of sustainability, water quality, and demand.

Changes in the idea of sustainability were characterized by the focus on aquatic health and the reorientation of the vision of point source pollution to diffuse, reflected in the logic of water quality that has become more restrictive with standards and monitoring based on aquatic ecology.

The demand was characterized by the emancipation of the end-user and the growth of expectations related to urban amenities and environmental protection. The infrastructure model, identified with engineering expertise, evolved from civil engineering based on forecasting and control to a more significant multidisciplinary approach, in which adaptability and flexibility became important design parameters.

The decision-making logic also evolved from the seventies, when it was characterized by bureaucratic, paternalistic decisions, centralized in powerful, vertically integrated organizations, and focused only on water supply, treatment, and drainage.

As of the 1980s, the government's influence grew, with the private sector participating and the predominance of the economic efficiency viewpoint. Decisions considered economic factors first, causing the user-pays principle to take the place of the tenure principle, which had property as the determining value in pricing decisions. As of the 1990s, this vision intensified, reflecting free-market competition, with a commercial focus and financial instruments in decision-making. Public-private partnerships, for instance, are considered an alternative, and the user acquires the status of a consumer. This framework remains from the 2000s with the water markets (Fonte 2020) when, however, due to the "millennium drought", at a critical moment, " a critical juncture", according to the definition of historical institutionalism (Monaghan 2021), the logic of risk comes into play, temporarily interrupting decentralization with the construction of large centralized desalination structures in all major cities (Brodnik et al. 2017).

Australia has a federative system of government commonly referred to as "Commonwealth" or federal, with six states and two territories and a constitution, proclaimed in 1901, which defines the roles of each of the eight federal entities and, according to section 100, water management is the responsibility of each. In the states and territories, there is another level of local government, which are the municipalities and district councils. In most states, the state governments own the utilities and local governments do the planning and management of stormwater services and the systems are separative. For over thirty years Australia has been developing its national water quality management strategy. It includes the use of stormwater for supply and guidelines are available for adoption by the states and territories. There are also guidelines for the evaluation of Water Sensitive Urban Design (WSUD) options that incorporate an integrated approach to the urban water cycle. This includes the management of water supply, sewerage, groundwater, stormwater, land use, and environmental protection.

#### 7.3.4.1 The Salisbury example - South Australia

The city of Salisbury, located in the Adelaide metropolitan area (population 1.3M inhabitants) in the state of South Australia, developed through rapid urbanization from the 1970s onwards, has today around 137,000 inhabitants and an average annual rainfall of around 430 mm, mostly occurring in winter, and has adopted WSUD principles to maximize the use of run-off water and reduce the risk of flooding. Aquifer recharge management was introduced to control the low salinity of stormwater by using Aquifer Storage and Recovery (ASR) in a brackish aquifer for subsequent irrigation.

The stormwater is collected in retention basins forming wetlands and lakes and subsequently infiltrated into the aquifers, with retention time around seven to ten days, being recovered through ASRs or Aquifer Storage Transfer and Recovery (ASTRs) allowing the reduction of the demand for water supply used for irrigation of sports fields. Wetlands now occupy about 200 ha of the catchment area and in 2001 the City of Salisbury expanded the use of urban stormwater as a commercial enterprise through a public-private partnership project. The project focuses on applying AUD$ 4.5 million to construct wetlands and ASR facilities for stormwater treatment and storage, at Parafield Airport, a secondary airport in Adelaide. In this case, also a purple pipe network was constructed, for the Mawson Lakes neighborhood, with recycled water comprised of a combination of stormwater from the Parafield Airport wetlands and wastewater from the Bolivar Sewage Treatment Plant.

The success of this operation led to the formation of a pioneering business that included nine projects in different locations. Providing non-potable water in a volume equal to 5 x 106 m³ per year, showed that stormwater containing contaminants, when stored underground and under control, can be used for uses such as irrigation of public open spaces and, when chlorinated, can be supplied in pipes (third pipe supplies). Its use for potable purposes depends on the additional use of microfiltration, UV disinfection, and chlorination, but the costs of these additional operations, to reach the required safety standards, are considered to be lower than the costs of laying double distribution pipes. The total cost of supply (capital and operation), for example, in 2012/13 was AUD$ 1.57/m³ for non-potable use for irrigation of public spaces and AUD$ 1.96 to AUD$ 2.24/m³ for potable use (excluding distribution network costs), therefore cheaper than the usual AUD$ 3.45/m³ for mains water (Radcliffe et al. 2017). The costs of providing non-potable water through a new distribution network, however, are similar to or higher than the costs of distributing water from the existing network.

In 2010 a business unit, Salisbury Water Business Unit, participating in the administrative structure, administered by the SWMB and chaired by an external independent member, was established. The unit manages various water collection and supply schemes for non-potable use, being mainly recycled rainwater and native groundwater. Treated to standards, according to the purposes for which they are intended, it is distributed to parks, reserves, schools, industries, and some residential sectors. It serves over 500 users, among them 31 schools and generated AUD$ 2.8 million in resources in 2015-2016.

#### 7.3.4.2 Melbourne and Victoria

In Greater Melbourne, 5 million people live in an area of about 10,000 km² with an average annual rainfall of around 600 mm (Meteorology 2022). There is a fixed annual charge per household, based on property value, which is paid as part of the Waterways and Drainage Charge, regardless of the amount of waterproofed area and the impact it has on drainage systems. In the Australian state of Victoria, the Water Act governs how the Waterways and Drainage Charge should be implemented, but it is unclear how the level of waterproofing may influence the levy. The theoretical graph in Figure 7.3 demonstrates how the fixed charge works allowing a reflection on the greater possibilities for incentives for non-sealing that can exist from a variable charging policy (Vietz et al. 2018), which is fairer, collects more resources to support the systems and provides incentives to non-sealing and disconnection. These can alleviate the need for extensions and maintenance on stormwater systems and save resources more efficiently.

## 7.4 Results and discussion

Unlike decades ago, when stormwater management was focused only on urban flooding, there was an evolution that, however, presents differences and similarities in developed and developing countries. The main issues involve multiple aspects and challenges such as water and environmental quality, aquifer recharge, supply and treatment, urban heat islands, urban well-being, street trees (Stovin et al. 2008) aquatic life, landscaping, and leisure, flood analysis (Burgan & Icaga 2019), among many others (Barbosa et al. 2012).

Although interrelationships between stormwater and wastewater are known, in several countries, especially somewhere the absolute separator system is adopted, at least officially (as is the case for Brazil), management is still focused on wastewater treatment. This is partly due to the significant sanitation deficit (ANA 2017), and stormwater is erroneously considered a low priority, except when flooding events occur (Tasca et al. 2017).

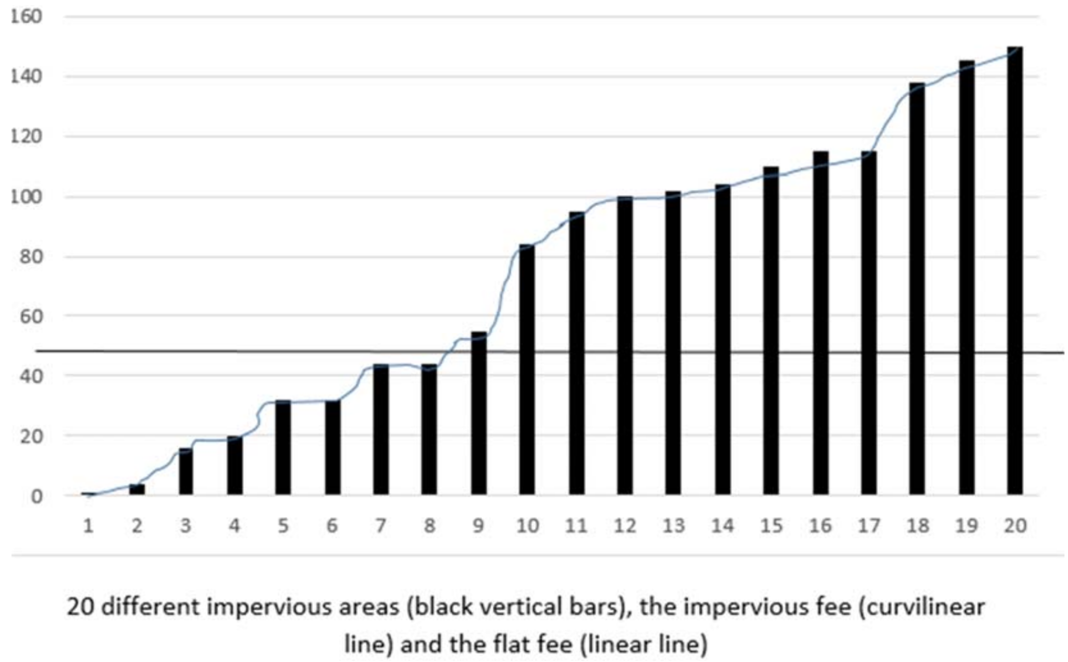


Figure 7.3 - Comparison between fixed and variable rates considering the same total storage for 20 dwellings with different degrees of waterproofing (Vietz et al. 2018).

Thus, the collection of stormwater fees and the construction of management structures dedicated to urban stormwater management, with or without private sector participation, has been left behind, especially in developing countries. Initiatives for its implementation are the target of many objections, including judicial ones, as was the case in the municipality of Santo André, in the ABC Paulista, metropolitan region of São Paulo. After a period of evolution and success in the use of charging, started in 1998, a setback occurred with its suspension in 2012 (Tasca 2016).

Experience, however, including in the U.S., has shown the importance of information and disclosure, particularly when on user demand, with the most used channel of communication with the public being the website (Black and Veatch. 2021). The Web aims at the understanding, involvement, and participation of society and the reduction of objections, proposed mainly by non-residential users. The objection questions are mainly of two types: the legality of the authority responsibility for issuing, implementing and financing the fees and the legality of the charging mechanism (Zhao et al. 2019).

The organization of management through SWUs considers the institutionalization of the application of fees as an economic support strategy for stormwater management. It is based on four criteria: efficiency, equity, adequacy and feasibility in the collection and use of revenues. It enables long-term planning of capital and operational investments, brings the potential for change in public behavior, impacts business and management of municipal investments, but at the same time suffers objections from users, including legal ones.

The tariffs, in general, are based on the operating, maintenance and, when possible, the capital costs of the systems, distributing them among the users according to criteria that, in most cases, correspond to the waterproofed areas. The criteria seek equity not only through proportionality between tariffs and the contribution to runoff and pollution generated, as established by the user-pays principle, but through different payment capacities, expressed, for example, by property values or consumption of services such as water supply.

The issue of stormwater systems support is still quite controversial, even in places like the USA and Canada, where there are legal challenges, most of them being refused by the courts. Barriers to their implementation also exists, as can be seen in the Canadian example of the city of Thunder Bay, where the conclusion led to the option, even in the short term, of not adopting the fairest method of distributing the burden of waterproofing.

There are several ways of organizing and funding stormwater management services, but they can be summarized in two, especially with regard to fundraising: the traditional model, based on the general budget (payment by all citizens), and the model based on payment just by the users of the service, known as the stormwater utility.

These two different visions on how to obtain resources to economic support public services are part of a larger dispute involving the role that governments should play in the solution of socio-economic-environmental problems. The traditional vision is opposed to the innovative vision of stormwater utilities, the latter responding in part to the population's desire of more fair tariffs and to reduce the burden of general taxes, as occurred in the USA decades ago, when stormwater utilities were implemented. However, decades after their implementation, the thought that they are hidden taxes disguised under another name still survives.

Existing experiences and those under implementation deserve to be observed and examples extracted from them of what may work and what may not work so well in each context. However, they should not wait, as this is still a subject that deserves practical experimentation, a kind of learning by doing, given the increasing demands that are coming with the growth of urbanization, rising temperatures, increased urban rainfall and rising sea levels, according to climate change forecasts.

For example, in Brazil, where the focus is still very much on the scarcity of public resources, the introduction of management and funding mechanisms such as SWU, based on the user-pays principle can work. As in other countries, in Brasil stormwater utilities are welcome, as long as they are applied through policies that encourage not only the economic contribution of users, but that consider forms of management with focus on results. Besides that, they may lead to increase the involvement and participation, bringing the contribution of all actors to the decisions made, including the design of the calculation methods of charging and the legislation. This may mean opening the way to solutions that lead to economic autonomy of stormwater services management and also for disengagement from the general public budget, decreasing taxes, with responsibilities distribution efficiency gains and a permanent flow of resources to the sector, providing sustained continuity to the actions.

The study shows that the use of the stormwater utilities mechanism is more developed in countries where environmental legislation has been fully implemented. Table 7.4 shows examples of the country’s main approaches, fee criteria and objectives. From the information in table 7.4, although it is not possible to verify uniformity in all aspects, there is a trend in the approach to control environmental effects (reduce pollution of water bodies) and in the criteria for calculating tariffs (sealed areas).

However, there is no definite trend regarding the form of quantification of the objectives, a fact that can be attributed to the experience and reality in each location. From the perspective of the economic efficiency objective, information on collected revenues compared to measurable cost outcomes of avoided environmental impacts (e.g., volumes of treated effluent) can allow for the ranking of Stormwater Utilities initiatives. Measured economic parameters also enable the comparison with other alternatives such as the overall budget itself.

This is different in countries where there are no legislation incentives or, as in Brazil, where the law has existed for a long time and is broad, but encounters obstacles to application. Utilities with a low level of institutionalization and, administrative and economical disorganization, tend to relegate environmental issues, postpone the acquisition of economic support and, eventually the funding and organization structure.

## 7.5 Conclusions

The overview of SWUs presented here provides an update on what has been done to ensure the economic sustainability of urban stormwater management systems with the participation not only of the public sector but also of users and private agents, being remunerated as a public service to society as a whole.

The study's contribution comes in the sense of bringing together scattered information and thus allowing the formation of a general picture of the evolution in a certain direction, namely, the economic organization and financial sustainability of urban stormwater drainage and management under a new paradigm, which has been occurring simultaneously in several places around the world. The perception of this fact as a general trend does more by allowing scholars, researchers, and practitioners to identify it and become aware of what is still missing for its rapid institutionalization, implementation and experimentation, thus contributing tothe evolution and improvement of the sector's actions. This is a small contribution, given what still needs to be done, but with the potential to help transform the reigning mentality or the business as usual, and in this sense it can be significant.

The institutionalization of charging users for the provision of urban stormwater management services, whether provided by public or private operators, always encounters obstacles, posed by those who believe that they should be compulsorily provided by the public authority and funded by general public budgets, which means the cost is socialized for all the society. Either due to technical reasons, such as methods of quantification of the shares that each one is responsible for (the user-/polluter-pays principle), or to issues of understanding regarding the services to be provided by the state or for various legal and rights-based reasons (i.e., legal, among others), the fact is that barriers exist to the implementation concept of stormwater utilities.

Table 7.4 - Countries, approaches, fee criteria and objectives.

| Country | Main Approach | Practical Fee Measures Criteria | Objectives Evaluation metrics |
|---|---|---|---|
| EUA | Environment<br><br>Pollution Control | ERU<br>(m² of impervious areas);<br>Many others<br>(flows, etc.) | Pollution and Environment Statements attendance |
| Germany | Environment and Equity Polluter-Pays Principle | Impervious area and water supply consumption | Impermeable surface reductions, groundwater recharge and treated quantitative vol. reduction |
| Canada | Polluter- Pays Principle | (m² of impervious area) and “ad valorem” property tax | Impermeable surface reductions |
| Australia | SUWM – Sustainability Urban Water Management | Fix, based on Property values | Groundwater recharge measurements; Stormwater and reuse non-potable supply |
| Brasil | Flow Control | m² of impervious area | Undecided |

The reality, however, has shown that in several countries, there are feasible ways of charging equitably for the services, relieving public budgets, encouraging the reduction in impervious areas and the disconnection to urban stormwater systems, i.e., saving nature from its impacts, taxpayers from unfair costs, and public budgets from unplanned expenses, made to remedy sudden failures, after extreme precipitation events, which are increasingly frequent, due to the climate.

Based on theoretical knowledge, expressed in various pricing and collection formulas that have been tried in practice in different countries, it is possible to see that economic sustainability, as the economic side of the ongoing paradigm shift in urban stormwater management services already has feasible options and alternatives. Thus, the argument that urban drainage is a public service left "for later" due to lack of resources or economic organization does not hold. Political will can set in motion policies, institutions and regulations that, aligned around the objective of solving drainage sector issues, set in motion incentives for economic organization and financial support.

The novelty is the possibility to make the economic change a viable side of the stormwater paradigm shift, in a win-win manner, with more than economic gains for all actors. There are efficiency gains in terms of environmental, social, institutional, organizational and political aspects.

This is not all, since society's acceptance of the paradigm shift, through the understanding of the gains that are thus produced, requires an effort of awareness. This is not only motivated by economic-financial gains and reasons, but by others of ideological nature, that is, at the level of ideas and ideals, as it is the case of the sustainable development goals. SDGs are present in the paradigm shift, but are not always perceived and requires more work from all. A missing economic aspect that is important in ascertaining the speed of the paradigm shift is the quantification of 'green' and 'grey' infrastructure investments made with the revenue raised through SWUs. This is an aspect for study, that is, it is important to know to what extent the mechanism and the collection from users has contributed to the implementation of more infrastructures that favor the paradigm change (e.g., green infrastructures) like the quantity of street trees and many others leveraging the change. Criteria to measure the achievement of clear objectives make the possibilities of reaching them visible, contribute to adjustments and can help everything run more quickly towards the change in paradigm.

The study explored the existing publications, information, and data to which it was possible to have access and, by adopting this methodology, it carries with it the limitations arising from it, such as the absence of information that does not exist in the databases studied, or even the form of research used in these bases. Additionally, given the dynamics of the temporal evolution of the experiments, they will continue to occur, often surpassing the ability to become aware of them and analyze them, a fact that is part of the research process.

# 8. ATTRACTING THE PRIVATE SECTOR TO URBAN STORMWATER: A FEASIBLE TASK OR JUST A PIPE DREAM?

This chapter was published in Water 2022, 14(14), 2164.

https://doi.org/10.3390/w14142164

## 8.1 Introduction

An important aspect of the institutional arrangement of the water sector (WSS) is the different degrees of private sector participation (PSP) in the provision of the corresponding services and infrastructure (De Souza & Barrocas 2017). Issues of cost, efficiency, and investment are usually arguments in favor of private participation in service delivery. Limitations on public budgets and greater management efficiency by the private sector, by its very nature, and objectives of cost recovery and return on investment, are part of this context. The existing public resource limitations added to aging infrastructures, climate, and demographic changes increase the necessity for investments, creating urgency in applying new sources.

In Brazil, the issue that bothers and mobilizes the actors around PSP, which to this day is very low in the country and tremendously low in stormwater management, is the low degree of inclusion or poor universality and weak quality of the services provided.

Without addressing other and diverse reasons for this poor performance, the debate has been restricted to questioning what types of providers could break this cursed logic that has resulted in 35 million people without access to water and over 100 million without access to sanitation services, with the consequent impacts on the health and economy of Brazilians. The panorama in stormwater management is even worse (Novaes & Marques 2022).

If only the change in the origin of the capital invested and the execution of well-designed contracts between the municipalities and operators were sufficient to achieve universal access and the provision of quality services, everything would be solved the next day, but the reality is quite different and PSP, although it is welcome and should have coherently constructed contracts, requires much more than that and provides challenges that must be gradually overcome, some of which are presented in this research.

In the case of urban drainage, due to its unique characteristics, in addition to the complexity brought about by its interrelationships with other sectors such as urban planning, health, economy and it’s low level of institutionalization, including concerning possible economic and financial support through pricing, the design of the PSP is a subject that requires intelligently creative and innovative solutions, with different local aspects that make its approach in a single text practically impossible.

Throughout the 1990s, private participation in the WSS sector was widely considered to be the solution to sectoral problems, specifically the lack of investment and inefficiency, but in the following decade, the vision changed due to several reasons, among them the insufficient engagement with finance in developing countries and the lack of clear conclusions about the benefits of this participation.

The World Bank emphasizes in a 2003 Operations Evaluation Department report that: “Private Sector Participation (PSP) is not a panacea to deep-seated problems and cannot be expected to substitute for decisions that only have the power and obligation to make. PSP is better likened to a sharp tool. A capable government can use it to great advantage to improve the water supply and sanitation situation but an inept government can make worse through an injudicious use of PSP without providing clear quality and price regulation and lending strong and sustained support to PSP” (Krause 2009).

Usually, the question of whether services are provided through public or private initiative takes second place, because what the population wants is for services to be subject to good performance including their governance, which leads to expected good results by the execution of the objectives outlined by public policies and good decisions made by those responsible for them (Vargas & Lima 2004; Tortajada 2010).

The relationship between political governance and WSS governance and performance aspects of the provision of services, such as the expansion of coverage and the efficiency of providers, should be analyzed, as their impacts can be positive or not. In political governance, institutions, as the main elements, shape the relationships between citizens and government actors (political rights and electoral systems) and the rules that determine government organization (separation of powers, checks, and balances), and in WSS governance the main aspects are the institutions, borders, and coordination in the participation of actors.

Institutions are the main elements of governance as they shape the behavior of the actors responsible for policy-making and policy decision-making. In the WSS governance, in addition to the coordination between the actors responsible for policy-making, services provision, and regulation, the participation of users and the definition of boundaries between all actors are important (Tortajada 2010).

In practice, the degree to which the existence of PSPs has a positive contribution to the provision of WSS depends on the overall country environment and institutional context (Mumssen et al. 2018). In Chile, for example, before privatization, as public providers, there was good quality of political governance and governance of the WSS sector (Krause 2009).

There are examples of successes and failures of public and private participation (Buenos Aires, Paris, and Berlin) in a pendulum movement, depending on each context (Hall et al. 2013).

Europe, starting in the 1990s, with the Urban Wastewater Collection and Treatment Directive (UWWD), following the concept of sustainability defined by the UN, had added environmental, ethical, and equity costs to the economic ones.

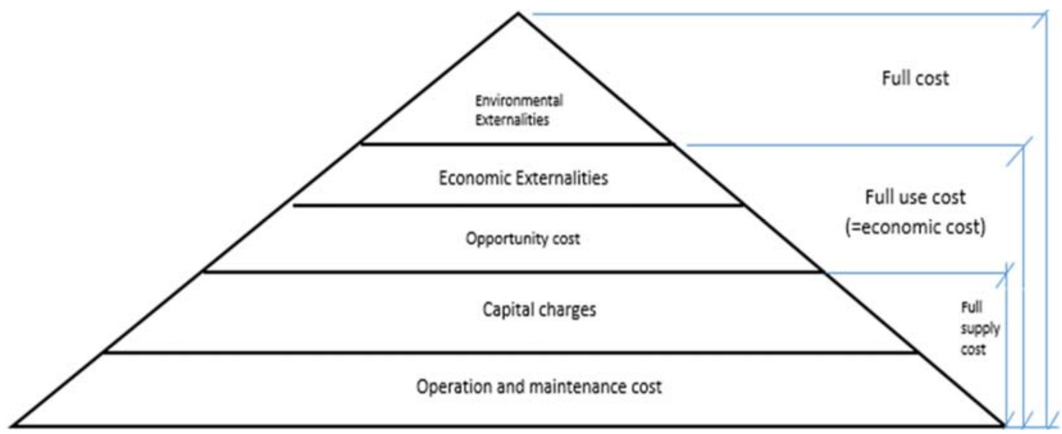


Figure 8.1 - Components of the total cost (Rogers et al. 1998 adapted).

The so-called three E's - economically, environmentally, and ethics and equity (Barraqué et al. 2006), however, can be summarized in the form of questions posed by water policy analysts (EUROWATER partnerships):

If we do invest enough, what impact will this have on water bills? – Economically Issue

How much more should be raised to upgrade environmental performance? – Environmentally Issue

If all sustainability costs are to be passed on to users, can they afford it, and is it politically acceptable? – Ethics and Equity Issue (Barraqué et al. 2006).

As one of the advantages listed for private participation (greater efficiency and flexibility in management and investment capacity), traditional costs are well known and usually taken into account (full supply costs). However, with the discovery of other costs, hidden by the former, the new distribution of costs, as shown in figure 8.1, including those impacted by a new distribution of risks between public and private participants, deserves to be reviewed to achieve economic and financial sustainability of WSS (Marques & Berg 2010). This sustainability could be achieved using equilibrium between costs and sustainable value in the use of water which should be equal to the full cost (Rogers et al. 1998).

The revisited new composition of the total cost parcels, to achieve economic and financial sustainability, must not only cover the determination of which portion should be borne by users, i.e., being collected by local governments, their concessions and partnerships, and through tariffs including subsidies, but also of which portion should remain with all taxpayers, through taxes collected for the general budget of the States.

The treatment and use of stormwater on precipitation site is an additional alternative to traditional systems, for example, with separate systems, one for stormwater runoff and the other for wastewater, or a combined and treatment system. However, from the moment that stormwater starts to be seen as a resource, and made available for potable and non-potable uses, a higher degree of complexity will be added to the calculation of costs for each parcel, public or private, making the design of the financial and economic sustainability of urban stormwater management systems more complex than that of potable water supply and sanitary sewerage (Novaes & Marques 2022).

Furthermore, in most municipalities there is no breakdown of costs, making them practically unknown, which makes it difficult to calculate them for various purposes, including those related to possible contracting or partnerships with private entities.

In cities where economic sustainability is based, at least in part, on one of the three T's of the triple bottom line of service delivery systems - tariffs, taxes and transfers (Machete 2021), charging for urban stormwater management costs can be determined in several ways.

It can be calculated, for example, from the volume of water supplied, as is performed in many places for the costs of runoff and wastewater treatment systems, or based on estimates of the amount of surface area on each plot, as is the case with most stormwater utilities in the USA and Canada (Campbell & Bradshaw 2021).

Thus, methods are usually used to estimate the volumes of runoff from lots, considering, in addition to the areas (total and sealed), infiltration factors, use (e.g., residential, commercial), property value, and several others, or just by applying a fixed value, not always linked to any specific parameter, but in general linked to operating and maintenance costs and sometimes the necessary capital investments. The other types of costs, environmental, ethical, and equity, remain a challenge so far.

This chapter aims, through the discussion of case studies, to present some existing forms of private participation in the management of urban drainage services in different places, some of which are still under construction and in progress, but with potential for success, to contribute to the ongoing discussions, providing evolution for the subject and consequently of the sector. Particularly, it discusses the Brazilian case-study, shedding light on the main issues and recommendations for PSP success.

The subject is organized into five sections in addition to this brief introduction. Section two deals with attractiveness and efficiency of PSP. Sections 3 and 4 set out international and Brazilian experiences. Section 5 summarizes and discusses the results of the international experiences focusing on the Brazilian experience. Finally, section 6 draws the main conclusions of the chapter.

## 8.2 Attractiveness and efficiency

In the private sector, the driver for attractiveness is the opportunity to monetize capital, while in the public sector, it is the search for the best service provision along with lower costs, and greater breadth and equity. Thus, attractiveness is linked to the costs involved, whether purely economic, environmental, or social.

Investment costs are more significant than maintenance costs; however, those related to flooding should be accounted for, even if under the heading of environmental expenses. For unitary systems, which are still the majority (50% or more), the expense of overloading treatment facilities during flooding also deserves to be factored in.

Concerning efficiency, in the private sector, there are management standards represented by extensive voluntary Standardization (e.g., ISO 9001 and ISO 14001), and in the public sector, it is present through regulatory requirements (Tovilla & Webb 2017).

In Brazil, however, the absence of precise information on the demand for drainage services leads to cost estimates based on the calculation of average production costs, prioritizing the financing of the system and cost recovery, i.e., neglecting efficiency, since all expenses (necessary or not) are distributed by the customers of the services, which is a disadvantage in terms of not taking advantage of the capacity to produce efficiency in PSP. The option of estimating an average cost is considered a second-best solution, if compared to the alternatives of social marginal cost or cost according to marginal benefit that considers price-demand elasticities. One advantage of PSP in drainage is the possibility of rescuing the idea of efficiency in urban land use through the quantification of the costs involved in its sealing.

In PSP, there is a division or sharing of risks between the public and private sectors, as in the case of PPPs, which have been extensively discussed, where the presence of guarantees provided by partners is intended to reduce risk; this is understood as the multiplication of the probability of occurrence by the magnitude of impact caused if the risk in question were to occur. In the case of the participation of private owners of the lots, through their reduction of flows or even their total disconnection, the costs of the devices implemented in the lot may be borne by the private owner or receive incentives such as a reduction of tariffs or subsidies for the implementation. It should be taken into account that there will always be centralized systems and that, therefore, not all should be encouraged to disconnect because the maintenance of the systems would be without resources, that is, there is an ideal number of incentives for each location.

Another form of PSP is the partial or total privatization of companies belonging to the public authorities, as is currently happening in Brazil, the most recent case being that of the Rio de Janeiro State Water and Wastewater Company (CEDAE), which was put up for public auction in which a concession was offered as payment to the State, but without any link to the application of resources in the sector. The company was granted a long-term concession through an extendable contract.

PSP can also be made by offering shares on the stock exchange, as in the case of the Companhia de Saneamento Básico do Estado de São Paulo (SABESP) which has shares on the São Paulo and New York stock exchanges. In this case, an inconvenience concerns the profit distribution percentages that sometimes exceeded the minimum stipulated in regulations. Thus, the reasons for not making investments to reach the universalization of services or to execute works to improve quality and resilience in times of scarcity are questioned. The participation of private capital through shares quoted in the market makes urges management to seek efficiency, as demonstrated through profitability with consequent valuation and attractive investments, but the balance between the necessary investments to serve the customers, the tariff affordability, the expansion of the operation, and the profits to be distributed using dividends to the shareholders, require professional management. In this scope, drainage is left to the municipalities with no such participation in the market, requiring new, creative, and attractive solutions that sensitize the actors with potential interest.

Finally, an important factor of attractiveness is the existence of public policies that favor PSP, such as flow reduction policies, because they signal a reduction in fixed expenses (with less construction and equipment) which, over time, generate a reduction in variable expenses for operation and maintenance of these infrastructures, that is, a reduction in total costs. On the contrary, negligency in this area becomes very expensive because by not designing a policy to restrict the increased inflows, the growth of costs and eventually inefficiency is accepted with the possible reduction of attractiveness to PSP.

In addition to cost reduction policies, there are policies to increase revenues such as rainwater reuse or utilization policies, which are considered policies that increase the attractiveness of PSP.

The use of the analysis tool based on the SWOT matrix, originally developed for strategic business and marketing planning, but also used in participatory planning (Andrade et al. 2012) can adopted for checking possible scenarios and policies for PSP in stormwater. Based on internal factors (strengths and weaknesses) and external factors (threats and opportunities) prospective scenarios are elaborated from combinations of these factors. The combination of (internal) strengths with (external) opportunities produces a first, so-called aggressive, or maxi-max scenario in which strengths and opportunities are maximized. A second scenario in which the weaknesses (internal) are combined with the opportunities (external) produces a conservative or mini-max strategy, in which the maximized opportunities (external) must compensate the weaknesses (internal) that are aimed to be minimized. In the third scenario, the strategy, called competitive, or maxi-min, the strengths (internal) and the threats (external) are combined and in this scenario the management of the strengths seeks to avoid the materialization of the threats. Finally, the combination of weaknesses (internal) and threats (external) produces a defensive strategy, or mini-mini, which seeks to minimize both weaknesses and threats (Takeleb et al. 2020).

Without exhausting all the aspects present in PSP in stormwater management, just as an example, we produced a SWOT matrix according to figure 8.2 below.

An example of a max-max aggressive strategy of forces and opportunities could be the design of a policy to encourage the use of rainwater as a resource (external opportunity) and intense use of private resources (internal strength) to finance storage devices on the plots through incentives to the owners.

A second example of a conservative or min-maxi strategy can be seen through the use of a policy of publicizing the stormwater utility (internal weakness) combined with intensified construction of stormwater amenity sites such as retention basins (external opportunities).

The competitive or max-mini strategy (reinforcing internal strength) e.g., by building works and equipment against floods and spreading preparedness for climate change and future uncertainties (external threat) is the third scenario. The fourth scenario is defensive or mini-mini can be exemplified with a policy of increasing the visibility of infrastructure (internal weaknesses) and fighting corruption (external threat).

| STRENGTHS (Internal factors) | WEAKNESSES (internal factors) |
|---|---|
| Capital needs for WSS<br>Fear population flooding<br>More health and well-being urban population demands<br>Urban demographic growth | Lack of dedicated budgets<br>Lack of knowledgeable staff<br>Lack of physical infrastructure<br>Low acceptance like as a public service<br>Low visibility of services |
| **OPPORTUNITIES (external factors)** | **THREATS (external factors)** |
| Control of heat islands<br>Creation of new infrastructure<br>Diffuse pollution control<br>Implementation of amenities<br>Optimisation of existing infrastructure<br>Rainwater/Stormwater as a resource | Climatic changes<br>Corruption<br>Discontinuity of administrations<br>Economic unfeasibility risks<br>General and local legislative gaps<br>Lack of commitment from political decision-makers<br>Lack of specific accounting<br>Lack of understanding of society<br>Unpredictability of the future |

Figure 8.2 - SWOT matrix for stormwater PSP

## 8.3 International private participation

In this section, the experience of PSP in the water sector and, particularly in the stormwater management, in six countries is presented. Cases studies of the USA, China, Portugal, Argentina, Germany, and Australia are discussed and the main lessons are displayed. Next section will focus on the Brazilian experience.

### 8.3.1 USA – Stormwater Utilities and PPPs

In the USA, Best Management Practices (BMPs) are generally adopted under the Low Impact Development (LID) approach and diffuse pollution from urban stormwater is a permanent source of concern as it threatens the quality of receiving bodies (Eanes & Zhou 2020).

Federal regulations for municipal separated systems (MS4s) have been in place since 1990 as part of the National Pollutant Discharge Elimination System (NPDES) to reduce sediment and pollutant loads from urban areas, but in Phase II, which covers municipalities with smaller populations (< 100,000 inhabitants), drainage plans are ineffective and stakeholders have little involvement (Rieck et al. 2021).

The main challenge is the control of diffuse sources of pollution using the local authority which has very little control over private properties that are responsible for a large proportion of the sources of stormwater runoff. In addition, the management task is made more complex by limited financial resources and the lack of recognition by the community that drainage and stormwater management are public services and should be understood as such, similarly, to water supply and waste collection, and therefore should have their own sources of funding such as taxes and tariffs that are accepted by all.

The lack of resources means that two alternatives are sought, the first through new taxes and subsidies and the second through the creation of stormwater utilities that can charge fees for services and use market mechanisms (e.g., discounts on tariffs for infiltration into lots for certain volumes) that encourage property owners to adopt stormwater management practices, even if these do not always abate pollution.

In Washington, D.C., a market has been created for stormwater credits that are generated concerning the reduction of stormwater runoff on properties. These credits can be traded in an open market where buyers need to meet regulatory requirements or, alternatively, they can be purchased by the Department of Energy and Environment, guaranteeing owners a return on their investment and providing private investment in certain areas of interest to society. At the same time, this stimulates the search for locations to install infrastructure with lower costs.

In a report concerning the responses of the participants of a Stormwater Utility Survey (Black & Veatch 2021) about public-private partnership (PPP) models, 50% of the responses indicated that the use of PPP arrangements was dedicated exclusively to the design, construction, and rehabilitation of traditional infrastructures under new concepts of BMP.

The main management activities included in the annual budgets are related to operation and maintenance and all issues show percentages of stormwater utility responses above 82%, except for maintenance of combined systems (66%) and street sweeping (66%). The low number of responses in these two issues, however, is due to the fact that there are no combined systems in most of the participating municipalities and that street sweeping is usually linked to other municipal departments, although it is understood that there is a connection between sweeping and drainage. One aspect to be highlighted is the inclusion of public education as the second most mentioned issue (92%) in the responses.

### 8.3.2 China – Sponge Cities Initiative (SCI) and PPPs

China is the country with the most experience in PPP arrangements (Pu et al. 2021) having grown greatly since 2014 with the development of infrastructure projects promoted by the central government. By 2019, 8031 PPP projects were assessed as viable by the Ministry of Finance, with approximate investments of about USD$ 1.8 trillion in January 2020, but there is no specific law regulating and supervising projects regarding PPP options (Pu et al. 2020) The Ministry of Housing and Urban-Rural Development (MHURD) did, however, produce a manual in 2014 that follows LID principles called "Technical Guidance on Sponge City Construction" (Wang et al. 2017).

With growing concern over flooding caused by rainfall events occurring in several major cities such as Shanghai, Wuhan (2016), Shenzhen, and the capital Beijing itself (2012) the Chinese government has adopted a series of policies and programs regarding drainage systems in cities, the most significant being, the national initiative called Sponge Cities Initiative (SCI) that was announced in 2014. This is a flood management strategy focusing on the environment and ecosystems, with the purpose rearranging the ongoing urban development process, to enable the reformatting of the ongoing urban development process, taking into account the urban water cycle (Jiang et al. 2018). Figure 8.3 presents the distribution on the fifteen of the thirty cities chosen as pilots for SCI and indicates the average annual precipitation (mm) (Tang 2019). The initial budget estimated about USD$ 1 billion for each one, plus investments from local governments and the private sector.

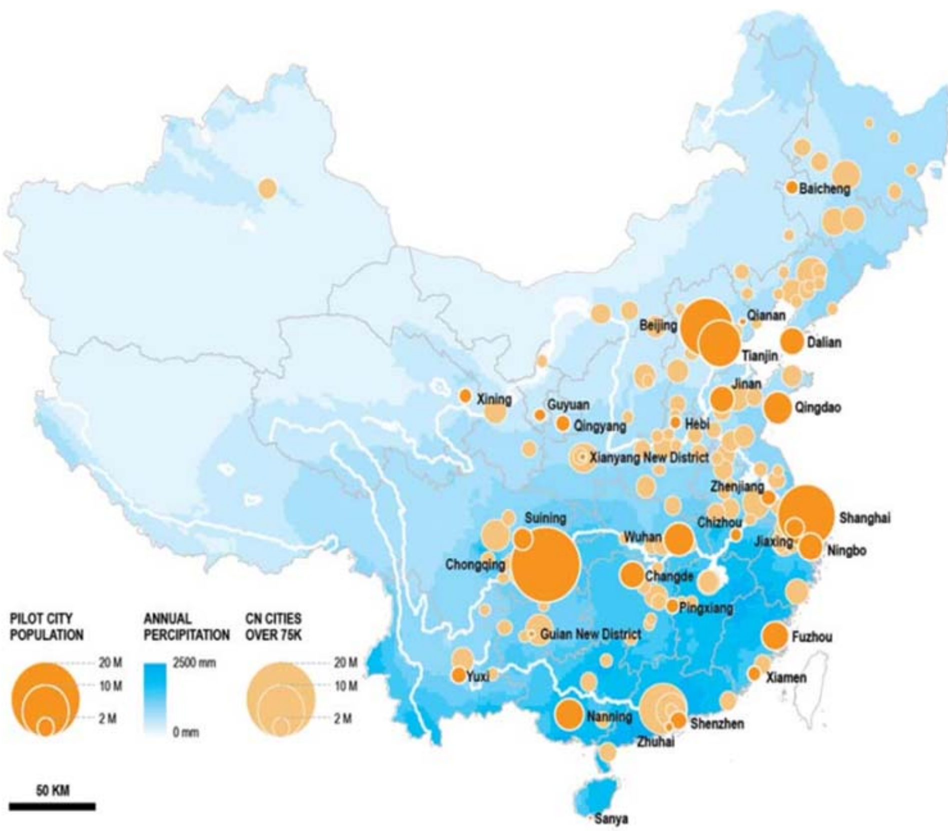


Figure 8.3 - Spatial distribution of the cities selected for the Sponge Cities pilot project with average annual rainfall (Tang 2019). Reproduced with permission from the author.

China, similarly to any country with large territorial areas, such as Brazil, the USA, Russia, Canada, India, and Australia, has a wide variety of geographic and climatic settings. Thus, considering cities with complex climates such as Beijing, located in the north of China in a semi-arid and semi-humid region where there are problems of both water excess and the scarcity of water, sponge infrastructures should take care of storing rainwater to reuse it in times of drought. In the city of Wuhan, for example, located in southern China, the rainfall is greater than 1000 mm and soils are often in a saturated condition, requiring the interconnection of traditional systems (modernizing them) with sponge systems. This demonstrates the need for distinct, specific solutions in each city. About 45% of the cities suffer from insufficient water supply and 17% from total lack of water, and of the 32 metropolitan regions with more than one million inhabitants, 30 face difficulties in meeting their demands (Jiang et al. 2018).

This great existing diversity, however, can be taken advantage as long as there is an exchange of experiences among the pilot cities, not only from China, but also from other countries where the solutions may be applied, but this requires that the costly learning methods to be stored and constantly updated.

Regarding the attractiveness of private financial resources, the development of business models depends on information and estimates of costs and benefits not only of sponge city projects but also of their comparison with the costs of traditional systems, which in China have accumulated rich experience due to the recent exponential growth of the country, including the application of modern technologies. This know-how is a factor that weighs in favor of traditional systems, considering that sponge cities, in contrast, are recent and still bring transaction costs such as integration between sectors, scope and learning, and execution time demanded by the projects.

Many of the advantages of adopting SCI are due to economic efficiency gains from benefits arising not only from economic gains, but from other multiple social and environmental aspects, which are not so easy to quantify, and from the interconnection of investment agendas with other sectors. All these factors are aspects that should be taken into account when designing a business model that can be attractive to private initiatives (Jiang et al. 2018).

The forecast of subsidies made by the Chinese government's Ministry of Finance for the 30 pilot cities is USD 60 to USD 90 million per year for each city during the first three years. The first group of 16 pilot cities is expected to receive investments of USD 13 billion during the first three years for an estimated total construction of 450 km² which translates to USD 29 million per km². According to the National Development and Reform Commission (NDRC), to achieve the planned amounts, the government encourages private participation through innovative arrangements such as PPP arrangements (Jiang et al. 2018).

Regarding society's perceptions and knowledge about SCI, such as its willingness to support the initiative through the payment of additional amounts in water tariffs or the purchase of government-issued bonds (3.9% return annual rate), a public opinion survey was conducted in 2016 in the cities of Zibo (4.61 M inhabitants) and Dongyingn (2.09 M inhabitants) Shandong province, one of the most important and industrialized provinces in China (third in terms of GDP and second in population), subject to rapid urbanization and has frequent problems with water supply and urban flooding (Wang et al. 2017).

The results showed knowledge of the SCI and its objectives and the perception that subsidies and PPP arrangements are the main forms of financing the initiative; furthermore, respondents accept the idea of a 17% increase in water prices to finance the construction of sponge cities. However, concerning investments, responses showed a willingness to spend, with the acquisition of SCI-related bonds, on average up to 55% of annual surplus income. China, therefore, emerges with a bold current vision for private investment and participation in the stormwater sector.

### 8.3.3 Portugal – A Hybrid Model on the Right Track

In Portugal, the responsibility for stormwater management lies with the municipalities, which can delegate their operation to the management entities through a specific contract. However, as there are two types of infrastructure systems, separate and combined, the former can be managed by two different entities, i.e., one for wastewater and the other for stormwater, although this may mean a loss of scale compared to the joint management that occurs in most systems, which are combined.

Decree-Law nº 194/2009 allows for joint management, although it does not clarify the form of cost recovery, and tariffs are subject to approval by the Water and Waste Services Regulatory Authority (ERSAR).

In the discussion of the Strategic Plan for the Water Supply and Wastewater and Stormwater Management Sector 2030 (PENSAARP 2030), it was considered to make stormwater management a responsibility of the wastewater services, and thereby removing it from the duties and responsibilities of the municipalities. Currently, the services are provided by the municipalities themselves itself, by municipal companies, or by concessionaires, and may be attached to the urban cleaning service.

However, whatever the form of management, one issue is the determination of the upstream and downstream boundaries of stormwater systems, with various types of reflexes such as the maintenance of urban cleaning (cleaning of gutters, drains, watercourses, and beaches).

Currently, even though municipal water companies have legal status under private law, what is also being discussed is the feasibility of the assumption by water customers of the fourth service in their bills, related to rainwater, in addition to water supply, wastewater, and solid waste, and the repercussion on the capacity of customers' budgets and the budgetary burden for the water services (Béraud et al. 2021).

The issue of resources to be invested, as demonstrated by the investment budget of the Lisbon General Drainage Plan - PGDL (2016-2030) which, for fifteen years, reached the figure of EUR 250 million (only the cadastral survey, completed in 2020, has a budget of EUR 1.7 million) raises the question of what is the best way to provide resources to finance the actions.

Thus, PSP in stormwater drainage and management services in Portugal still has a long way to go and will require the definition of several issues, including the form of participation and sharing of obligations in society, some of which have been raised in this text.

### 8.3.4 Argentina – The Privatization Experience

The private concession of WSS carried out in the metropolitan region of Buenos Aires presents aspects related to integrated water management that explicitly demonstrate the interrelationship between surface water, including stormwater, and groundwater. The region is located on the banks of the Rio de la Plata, a practically inexhaustible source of surface water, and at the same time is located up a system of underground aquifers of which the hydraulically connected Pampeano and Puelches aquifers are part (Sainato et al. 2000). These groundwater aquifers are water tables from a few centimeters to 5 m below ground level and extend up to 60-70 m in depth, suffering from overexploitation (Cruz & Busso 2002).

Despite the existence of aquifers, with good quality water, the concession only provided for the use of surface water, also of good quality, disregarding the possibility that the poorest areas could be supplied by groundwater, through the drilling of wells. Although accepted that this could happen while the concessionaire Águas Argentinas SA (AASA), from the Suez Group, did not carry out work in areas that still do not have access to surface water networks.

The initial proposal provided for the service of the entire population without any conditions, that is, the universalization of WSS regardless of the purchasing power, ownership, and infrastructure of the housing, until the end of the term of the concession contract (thirty years).

It should be noted here that issues of ownership, housing infrastructure, and provision of public services, which in periods before the concession were dealt with only between the municipality and the residents, now have a new entity: the private company. The recognition of the property rights and the right to access the WSS are two interconnected processes, and privatization carries conflicting aspects such as, for example, the resistance to paying concessionaires for connections to the network – which are up to USD 400 to 600 for water and USD 1000 for sewage (Botton & Merlinsky 2006) by customers who do not own legal lots, and are unsure of their permanence in the place. This is a matter handled by the government.

Universalization through the privatization of services strategy encounters difficulties related to the urban planning process of cities, especially in their poorest neighborhoods, exactly where the greatest deficits in the provision of WSS are found. The greatest deficits in land regularization and the infrastructures of stormwater are important parts of the system.

In the specific case of Buenos Aires, 25% of areas covered by the concession comprise a poor population (2 million people), making these issues very important.

From the late 1990s onwards, another relevant aspect regarding drainage, especially in the case of the metropolitan region of Buenos Aires, was the rise in the water table due to the closure of underground extraction wells due to the decrease in industrial activity, and also the contractual policy of using a single source of supply for surface water, plus the option of expanding the networks, with a relatively smaller increase in the sewage system and a great increase in the supply network (Botton & Merlinsky 2006).

The rise in the low level of the water table caused a decrease in the infiltration capacity of the soil and the increase in the number of supply networks without the counterpart of sewerage, which caused less water to flow out than enter the region, both caused, especially in moments of high levels in Rio de La Plata, urban flooding occurs. The population's perception of the connection between these flood events and the “single source” contractual policy with little drainage, created consequent dissatisfaction. This is a factor considered as one of the causes of the failure of the concession contract to the private sector.

The first water services concession contract was signed in 1993, immediately before the 1994 constitutional reform, and the Suez Group announced its intention to disengage from participation in Aguas Argentinas S.A. in September 2005.

The lessons taken from the Buenos Aires experience reveal that not considering all aspects involved in urban waters issues, in particular stormwater management, can jeopardize the feasibility of projects to universalizing the WSS.

### 8.3.5 Germany – Participation of Landowners in Berlin

In new neighborhoods and subdivisions, it is possible to implement decentralized urban drainage management by installing devices on the lots, and municipalities can make their own choices for decentralized drainage policies. However, in older neighborhoods, with traditional (centralized) urban infrastructure already in place, carrying out required incentives depends on instruments, that are generally supported by legislation and local rules, that lead owners to adopt them.

Research conducted in Germany in 44 municipalities addressed the incentives for owners to adhere to decentralized management and, from the point of view of the New Institutional Economics theory, two institutional aspects of municipal management of urban drainage, present in all municipalities, were analyzed: the first was the compulsory connection and use of existing networks, and the second was the taxes (from EUR 0.29/m² to EUR 1.93/m² with the unweighted average of the sample equal to EUR 0.85/m²) and discounts applied. The analysis took into account the interaction between institutions (interplay) and contradictions with the refinancing of the existing infrastructure, as well as the risk of loss of controllability due to the large number of people involved in management (Geyler et al. 2019).

In Germany, various mechanisms can be used to encourage the adoption of decentralization measures, and among these various other institutional aspects of municipal urban drainage management, such as land use planning, mandatory use of green roofs, local funding programs, information campaigns, and restrictions on the use of centralized systems have been implemented.

Ideally, the design of the institutions should be conducive to the achievement of the objectives, i.e., to get private owners to participate in urban drainage management, thus contributing to the municipality achieving its objectives, including the better urban flood control and lower drainage infrastructure costs.

Figure 8.4 shows two previous planning stages, the objectives and integration strategies of the owners, before the design of the institutions, and the two institutions under study, with the first being the compulsory connection and use of the networks, and the second the taxation of drainage systems. Furthermore, the interaction between the two institutions (the institutional interplay), the conditions for their adoption and operation, and the owners' investment decisions harmonized with the objectives and strategies previously planned are presented.

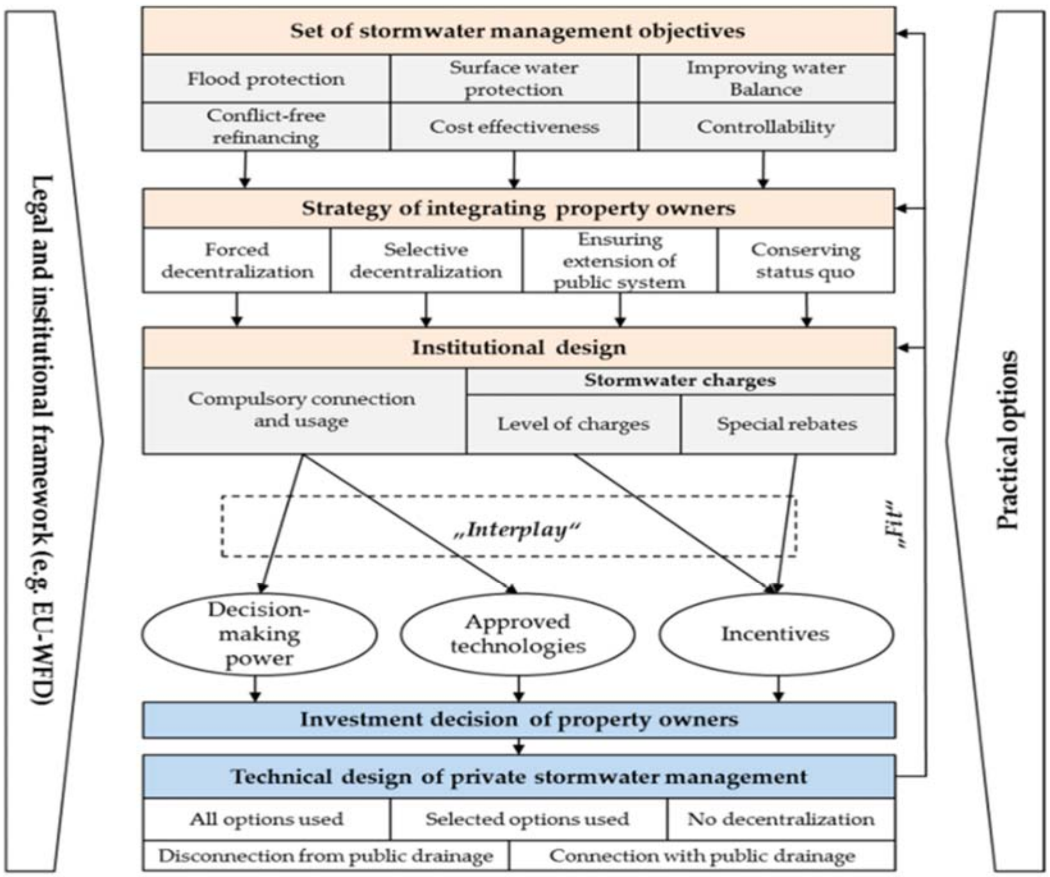


Figure 8.4 - Conception of institutional design - external influences and effects on private stormwater management (Geyler et al. 2019).

Two decentralization strategies (integration of landowners into stormwater management) can be implemented with landowners more likely to adhere to decentralization the higher the fees and discounts. There are two other strategies, which are considered to exclude landowners more in management. Thus, there are four different institutional conceptions: forced decentralization and selective decentralization (more inclusive of private participation by property owners in management) or, alternatively, an extension of the public network and maintenance of the status quo (more exclusive of private participation).

In the first case, for forced decentralization: there is no compulsory connection, the fees are high and many discounts are offered. The option is favorable to municipalities that are highly dependent on the contribution of property owners for the protection of surface water, for water balance and flood protection, and where a high potential for conflict over refinancing and a significant loss of control are accepted.

In the second case, selective decentralization, there is no compulsory connection, high fees, and no rebates. This concept promotes the protection of surface water against flooding, with the water balance receiving support from landowners, and may be the option for municipalities that accept high risks related to refinancing and loss of controllability.

The third case, guaranteeing the extension of the public network, combines compulsory connection with high fees and no rebates and can be chosen when it is desired that the owners contribute by co-financing the public system while maintaining a low refinancing risk and no loss of controllability.

The fourth option, status quo: is a combination of compulsory connection, low level of taxation, no special rebates, minimizing incentives for owners to decentralize, creates long-term controllability, ensures no refinancing conflicts. This is a good choice for municipalities where small charges can be supported to achieve the objectives of stormwater management.

Taxes are usually used to finance the existing systems under the vision of cost recovery, which can lead to high taxes according to the needs of these systems. Thus, policies of incentives to decentralization through discounts can lead to a certain number of disconnections from the network with a loss of revenue, but also a decrease in demand. On the other hand, the lower the charges and the lower the incentives for disconnection, the greater the possibility of maintaining the status quo, that is, of the systems remaining requiring ever greater resources.

Using geographical information system (GIS), it was found that even in densely populated areas of Berlin, it is easily possible to disconnect 30% of the impervious areas in a 22 km² catchment area with a separate sewerage system (Sieker & Klein 1998).

Taxes have an ambiguous role as both a source of revenue for the refinancing of existing public systems, but also as a source of incentive for the decentralization of the systems, which also makes them a source of revenue loss due to possible disconnections.

From an economic point of view, there are arguments against decentralization, such as the devaluation of investments already made and the risk of growth in costs and charges, combined with the loss of economies of scale and high transaction costs (Geyler et al. 2019).

Despite its advantages, the issue brings complexity by requiring the determination of the balance between the values of charges and the needs of existing systems, discounts for disconnections as incentives for owners, and the risk of loss of control over the management of the systems due to the greater number of participants.

#### 8.3.6 Australia – Water Markets

In Australia, the water sensitive urban design (WSUD) concept is widespread and separative systems have been implemented, but there is still a need to expand the knowledge of stormwater resource use within the urban water cycle, creating the possibility for more effective economic and business plans. Concerning the private participation through charging, the example of Melbourne can be cited, which in 2016 received AUD 6,645 /Kg per year for stormwater nitrogen loading (Radcliffe 2018).

In Melbourne, economic aspects had a strong influence on the private solutions adopted, such as PPP arrangements for large projects. They also acted as an incentive to build an additional private network for recycled wastewater supply. The existence of funding for the installation of rainwater tanks as an alternative source of non-potable water was also used as an incentive for the adoption of the solution (Ferguson et al. 2013).

The creation of a market for the transaction of water access and use rights, called the Water Market, was conceived in Australia as a way to address, especially in times of scarcity, the better balancing of use in rural areas, but despite the political and institutional constraints to its use in transactions between rural and urban areas, Adelaide, Bendigo and Ballarat have used this mechanism to circumvent urban scarcity problems (NWC 2011).

## 8.4 Brazil

Brazil has a long history of reactive actions to public service delivery issues, with very little planning. Here we focus on the specific aspects. Several issues contribute to this, such as the frequent change in political direction after elections; the reduced knowledge and participation of the population; the lack of institutionalization and organization of specific administrative structures; regulations being in infancy; corruption; diversion, and the poor teaching of current drainage techniques, among many others that may occur simultaneously or not (Novaes & Marques 2022).

Despite this terrible picture, several initiatives continue to be tried and deserve attention, and we will look at them to try to extract good examples for the evolution of the stormwater management debate.

### 8.4.1 São Paulo

In Brazil, there is a multiplicity of actions regarding urban stormwater drainage and management, especially in large municipalities, the most populous among them being the city of São Paulo. This metropolis opted, like 665 other municipalities, according to Basic Sanitation National Plan (PNSB) of 2008, for the construction of several temporary rainwater detention reservoirs as a way to attenuate the precipitation peaks and volumes in the municipal region.

In this municipality, PSP was considered in one of the last actions of 2020, through a PPP arrangement in the modality of administrative concession, i.e., the main payments to the concessionaire would be made directly by the municipality, additionally allowing the latter to obtain ancillary revenues. In this specific case, such revenues would come from the commercial exploitation of air spaces located above four existing stormwater detention and retention reservoirs (Sharp, Guaraú, Anhanguera, and Rincão). The main objective of the contract was the requalification, operation, maintenance, and conservation of the four existing reservoirs, as well as drainage interventions for the five micro basins of the municipality. The total expected value is USD 257 million over the 33-year term of the contract (Municipality-SP 2020).

Only by way of comparison, according to the recent Basic Sanitation National Plan (PLANSAB) of 2013, the estimates of resources to be spent on urban drainage in Brazil by region is presented in Table 8.1.

Table 8.1 - Investments in urban drainage by 2033 (PLANSAB 2013).

| | | | | | | | | | **Investments (millions of USD)** |
|---|---|---|---|---|---|---|---|---|---|
| | | | *Expansion* | | | *Replacement* | | | *Total* |
| Region | )14- 2018 | )18- 2023 | )23- 2033 | .4- 2018 | .8- 2023 | !3- 2033 | )14- 2018 | )18- 2023 | )23- 2033 |
| North | 932 | 1.045 | 1.665 | 106 | 203 | 427 | 642 | 1.248 | 2.093 |
| Northeast | 3.074 | 3.465 | 5.453 | 304 | 585 | 1.255 | 2.072 | 4.050 | 6.677 |
| Southeast | 3.529 | 3.956 | 6.140 | 1.100 | 2.166 | 4.359 | 3.129 | 6122 | 10.499 |
| South | 8.466 | 9.696 | 14.618 | 551 | 1.089 | 2.185 | 5.420 | 10.785 | 16.803 |
| Center West | 1.262 | 1.435 | 2.179 | 317 | 629 | 1.258 | 1.043 | 2.064 | 3.438 |
| Total | 17.263 | 19.597 | 30.055 | 2.378 | 4.672 | 9.454 | 12.306 | 24.269 | 39.509 |

### 8.4.2 Brasília – Federal District

In Brasilia, the federal capital of Brazil, located in the Federal District (DF), the responsibility for the provision of urban stormwater drainage and management services lies with the Companhia Urbanizadora da Nova Capital do Brasil (NOVACAP), according to District Law nº 4.285/2008 (arts. 51 and 52). Article 51 states that NOVACAP will be granted a concession contract with the Federal District's Water, Power and Sanitation Regulatory Agency (ADASA) for thirty years, renewable for up to twenty years at the discretion of the executive power and that a PPP contract will be signed to make the services economically viable.

When the legislator present in the law affirms the intention of seeking the economic viability of services through the forecast of PPP arrangements (article 51) and charging (article 53) indicates the intention of PSP, that has, as will be seen further on, not prospered (at least up to now), this characterizes a case of mimetic isomorphism, in other words, the copy of an existing model in operation in other contexts, but without its effective placement in practice. It is thus a contradictory situation between "de jure" and "de facto", as pointed out by some authors (Narzetti & Marques 2021).

NOVACAP, a public company, however, is not a specialized body for this activity and disputes tax revenues for many other purposes. Furthermore, the concession contract envisaged in Article 51 of the law, according to part of the doctrine, brings contradictions, since the NOVACAP company could not be treated as a concessionaire, since it is a political entity holding a public service and perhaps this is why such a contract was not signed (Montenegro 2019).

Besides NOVACAP, the Department of Highways (DER) is also in charge of urban drainage, since several highways cross the urban areas of the Federal District requiring the management of the interface between these agencies.

The economic and financial sustainability of these services, according to the same law (District Law nº 4.285/2008, article 43) provides collection in the form of taxes, following the regime of provision of services or their activities. However, more than ten years later had not yet been implemented, making it difficult to face the issues posed by the Urban Drainage Master Plan (PDDU) and confirmed by the District Plan of Basic Sanitation (PDSB) of the Federal District (DF 2017).

Article 53 of the same law (District Law nº 4.285/2008) provides charged public services for the drainage and management of urban rainwater taking into account, in each lot, the percentages of impermeable areas and the existence of rainwater damping and retention devices, in addition to other criteria such as income level of the population of the served area, the characteristics of the urban lots, the areas that can be built on them and the effective drainage area in the case of completed construction, evaluated according to technical criteria established by ADASA. However, the executive power has not yet taken any initiative to implement the charge.

Despite the absence of a specialized body to provide services and a specific source of resources for the financial support of the activity, ADASA has been carrying out several important actions to organize the sector.

Such actions include the elaboration of a drainage and stormwater management manual and the monitoring of the elaboration of the PDSB that identified the need for institutional development and infrastructure deficits. A review of the DF drainage system cadaster was also made, in addition to GIS development; the proposition of control of sediment generation by civil construction works, incorporated in the new DF Works and the Buildings Code and guidelines for public works.

Another work performed by ADASA was the assessment of the extent and composition of DF's public and private sealed areas through high-resolution images, as summarized in Table 8.2. Finally, the identification of options for the institutionalization of service provision, including the feasibility and legality of charging; modelling the charging structure involving sealed areas, social tariff, cross-subsidies, and other parameters to the assessment of annualized reference costs to be covered, was completed (Montenegro 2019).

Table 8.2 - Typology and extension of impermeable urban areas in the Federal District (Montenegro 2019 adapted).

| **Typology of impermeable urban areas** | **Area (m²)** | **Percentual (%)** |
|---|---|---|
| Public Common Use Impermeable Area | 213.864.804 | 44% |
| Private Impermeable Area (plots & projections) | 201.566.138 | 42% |
| Shaded Areas | 68.284.851 | 14% |
| Waterproofed area analyzed | 483.715.793 | 100% |

Table 8.2 shows that private impervious areas are approximately equivalent to public areas, suggesting the possibility of the joint participation of the public and private sectors in the

revenues to support the economic and financial management of stormwater drainage and management services in the Federal District.

## 8.5 Results and discussion

The objective of attracting private capital requires solid strategies, based on a vision of consolidated social interests and priorities clearly expressed not only in general public policies that have attractiveness as one of their objectives, but also in specific public policies that, for example, determine the priority areas of action, as seen in China, where pilot projects were concentrated in 30 cities. It was, however, the problem of floods and water scarcity that pushed action in the direction of Chinese sponge cities (Qi et al. 2020). Table 8.3 shows the main pros/cons and barriers.

Table 8.3 Main pros / cons and barriers to PSP

| Pros | Cons/Barriers |
|---|---|
| Other sources of funding | - Corruption & Inept governments |
| - Sharing risks between public and private | - Transaction costs |
| - Internalization of externalities | - Institutional and environmental contexts |
| - Greater efficiency in management | - Difficulty ways to measure before and after |
| - Possibility of using Project Finance | - Absence of policies aimed at PSP |
| - Possibility of regulation | - Lack of Regulation and inexperienced staffs |

From climatological and hydrological mapping combined with historical occurrences and the existing infrastructure in each place, one can have a starting point for determining these priorities. This alone, however, is not enough, as there remains the issue of quantifying the resources needed for the actions. This quantification requires knowledge of the cadasters and the updated situation of the infrastructure, in addition the dimensions of events with several return times and the respective associated costs. The determination of the technical structures (human and material resources) on which the responsibility and deadlines should fall to accomplish the tasks mentioned above, passes through the existence (or construction) of these structures and also the "rules of the game" for this to happen.

In large countries such as Brazil, China, and India, prioritization is part of the game, despite the importance of building national guidelines. However, prioritization requires knowledge of the problem and strategies for action, i.e., data, information, and planning, without which there is no business management towards solutions.

However, with a passive policy in the face of reality, in the simple expectation that the municipalities can formulate their demands for the supply of resources from the central government, as it has been happening in Brazil, an undesirable selectivity of municipalities occurs, without achieving the objectives for the application of available resources, nor the control and solution of the problems of flooding in the places where they are most critical. The choice for the allocation of resources based only on the existence of projects that comply with legal-accounting rules results in actions centered on municipalities that do not necessarily keep close correlation with the priorities and problems focused on by pro-active policies, which aim to solve them and present results, in well-defined time horizons.

The attractiveness of private capital must overcome this bureaucratic-technical frontier for the allocation of public resources and focus on the solution of problems without the restrictions required by the resources of public budgets, that is, the solutions must be the responsibility of the private capital, especially for its economic sustainability, making use of accounting by showing the expenses and revenues of the projects from a perspective more linked to project finance than to subsidies and governmental contributions, even if this requires extending the life of the projects.

In Brazil, the scarcity of resources in public budgets finally led to escape from the trap of the controversial debate between forms of capital (public or private) to be applied in solving problems related to WSS, especially the issue of universalization. By opting for the private capital and the increase of PSP, the need for its regulation is verified and so it is bet now on the elaboration of rules for regulation through a specific agency (Narzetti & Marques 2021). However, as a centralized decision solution, defined from top to bottom, without any participation of society, there is the risk of practicing a kind of mimetic isomorphism and at the same time forgetting the complexity of the sector, especially the local aspects, particularly expressive concerning stormwater management, and reaching questionable results.

Drainage pricing, in almost all charging initiatives, is vital to sustaining programs, as is the case in the USA, has proven sensitive to public understanding and support than when it comes to water supply and wastewater runoff. In Brazil, it should be similar and they should encounter barriers with the adoption of top-down solutions. Of all the sub-national regulatory agencies, only one (ADASA) has tackled the issue of drainage regulation without, however, addressing the pricing issues.

Under this view, projects deserve to broaden their objectives and include other systems than just urban drainage and stormwater management. The concession of areas such as zoos (Fagan et al. 2011) for instance, in which detention or infiltration basins can be included, may allow their financing through part of the entrance fees and other revenues linked to parks.

In the case of mapping, there is ample climatological documentation, which should, however, be permanently updated in light of climate change. In the case of Brazil, the National Sanitation Information System (SNIS) database deserves to be improved to apply the above vision.

In Brasil the coordination of this information (climate, infrastructure, and feasible concessions) requires the participation of staff structures that include people and resources to format projects which, if successful, can serve as an example so that other cases can be executed. This takes time and the implementation of this vision must urgently start so that know-how and private capital participation can contribute to urban stormwater management as soon as possible. In China, it is estimated that the experience should take a generation (Jiang et al. 2017).

## 8.6 Conclusions

Concerning PSP in urban drainage systems, there is a long way to go given the current situation, both in terms of independent organizational structures, cost segregation, and investments to be made. All, in turn, depend on political options, institutions, and management techniques such as, for example, the different policies of forms of use, e.g., resources, non-potable or potable, treatments, and decentralization, each with different applicable technologies (infiltration, aquifer recharge, green roofs, cisterns, disconnections, and impervious area removals). Through case studies in different countries, an overview of PSP in the drainage and stormwater systems sector has been presented, seeking to present the reasons that underpin the importance of PSP, as well as the pros /cons and barriers to its implementation.

The study aimed to verify, based on the idea that PSP can bring important contributions to the public services sector, with the main driving forces of attractiveness to capital and efficiency, how PSP has worked in practice, using urban stormwater management services as an object of study. A critical analysis of the relevant aspects found in several existing cases in four continents, but with a special focus on Brazil, was synthetically carried out, and characteristic aspects with the potential to be useful to reflection due to their singularities or similarities were presented.

The subject was approached in several ways, but brings greater focus on the economic aspects involved, which is a point of great relevance given the rise in the scarcity of public budgets, aging infrastructures, and climate and demographic change demands. The lack of a wider approach to the advantages and disadvantages involved in the other aspects can be considered one of the limitations of the work.

Finally, what is certain is the fact that within the urban water cycle, rainwater is becoming increasingly more important. Calling attention to its use leads us to demand the study not only of ways to use it, but also of the institutions and organizational structures involved in its management, as the existing and traditional ones are not adequate or attractive to private sector. Thus, by utilizing this resource appropriately, the challenges in stormwater PSP will become just another summer dream.

# 9. CONCLUSIONS

## 9.1 Achievements and concluding remarks

In this thesis, the current mentality, and its necessary change, with focus on the performance of the stormwater systems is analyzed, especially considering the policies put into practice in the sector, the institutions, understood as the formal and informal rules of the game that involves the players, the regulation of their results in face of the designed policies or, just their naturally expected goals, and governance, defined as the relationships that arise from the interaction between the players responsible for putting into practice the set of elements involved in Policies, Institutions and Regulation, here called PIR. The main conclusions found in this study are presented according to each of the chapters, which were transformed into articles, some already published in journals and others submitted for publication.

### 9.1.1 Chapter 1

By introducing the theme, also automatically introduces the main issues that drive the development of the thesis. It starts from what exists and seeks what is still missing for the good implementation of urban drainage. This path naturally leads to the need for a new management paradigm, which involves changes in mentality and in orientation regarding urban drainage and stormwater management, especially concerning the PIR aspects in which it is inserted. The message reveals questions about how best to bring about this change.

### 9.1.2 Chapter 2

The first question that presented itself to the study was regarding how the subject has been addressed by scholars, and the answer was provided through a hybrid literature review. The literature review, through which one had access to existing information in publications available from the 1980s to 2020, was conducted using a hybrid methodology. It was composed, in its analysis stage, of three steps: quantitative, semantic qualitative analysis, and narrative analysis, concluding that there is a growing interest in issues related to PIR as of the last ten years, distributed by a large number of authors, but still predominantly concentrated in countries such as the USA, Australia, and the United Kingdom. The semantic analysis, carried out with the use of specific software, making use of machine learning resources, produced as results a word cloud and a concept map that corroborated both the frequency of appearance of the themes, their relevance, and inter-relationship, which can be considered as a background and trend in the treatment of the subject. One notices that not only PIR's are present, but also themes related to paradigm shifts such as Best Management Practices (BMP), Green Infrastructures (GI), Source Control Techniques (SCT), and many others.

### 9.1.3 Chapter 3

The chapter dealing with institutions, considered the rules of the game, places them within a context of systems governance, understood as responsible for shaping, managing and changing the structures and processes of parts or all of society. Structures shape the institutional design and mechanisms through which the social order is produced and reproduced, and processes are activities for establishing and enforcing the rules of the game. Governance is a broad concept involving decision-making processes carried out by groups that alone do not have the power, knowledge, information, or resources to determine the course of action.

The question is how to institutionalize change and based on what factors. A paradigm shift requires changes in attitudes, norms, and regulation. This leaves questions such as: Which actors mobilize change? When and where do changes begin and end, and how do transaction costs behave? With the lack of participation, can drainage policy exist as a "policy without a public”?

The chapter concludes that the paradigm shift issue has a high degree of complexity due to the number of aspects and actors with different perspectives that are involved and reveals the importance of institutional issues for the transformation already underway. Besides involving a change of mentality, the transition from traditional to sustainable involves ideological change, i.e., in the systems of ideas, according to the three aspects: cognitive (want to change), normative (must change), and regulatory (be driven to change), which requires time, estimated at least a generation. One of the drivers for change lies in the efficiency gains that can be obtained in socio-economic and environmental terms that go beyond the sectoral boundaries of stormwater.

### 9.1.4 Chapter 4

Public policy regarding stormwater is inserted in the context of institutional inertia and path dependence discussed in the previous chapter, number 3. Decision-makers create policies based on the perception of problems that need to be solved. They use different instruments such as laws, regulations or funds to achieve previously determined objectives according to established priorities. In doing so, they modify institutional and regulatory structures, the other two sides of the PIR tripod.

Policies do not cease to be institutions either, and thus they are reflected in the institutions that coexist with them, and the same happens with regulations. In places where the paradigm shift finds a more favorable environment, such as Australia, stormwater policies, like WSUD, are successful and the paradigm shift is occurring with less difficulty. In places such as the city of Munich in Germany, this success can be verified by the reduction of sealed areas, which since 1995 have reached 4.5 M $m^2$.

### 9.1.5 Chapter 5

The chapter presents the last of the three parts of the tripod formed by the PIR’s, that is, regulation, another gap in the literature and practice, including in Brazil, where there are still doubts about its benefits and the value for money that regulation can add to drainage. The title contains this concern by stating that regulation is not a matter of choice, but performance. Regulation controls the results of policies, according to institutions, i.e., in line with the rules of the game, through incentives that are provided in soft ways, such as best practices guidelines, or hard through command-and-control instruments, including the provision of punishments and fines for bad performance.

The first conclusion is that regulation depends on a favorable institutional political environment, i.e., institutions that provide clear rules and policies with equally well explained and transparent objectives, defined based on consensus among the actors. The second conclusion, linked to the previous one, concerns Brazil, which expanded the expectation of improvement of WSS services from the edition of legislation in 2020, with the creation of national regulation. It is clear that with the absence of specific policies and institutions for stormwater management, i.e., with only regulation, part of the PIR tripod, well elaborated, there will still be gaps to be filled.

### 9.1.6 Chapter 6

Chapter 6 addresses the issue of sectoral interrelationships between urban services and other sectors. Based on the perception that there may be cross effects of one on the other the object for analysis is the relationship between urban stormwater and the health sector. To assess to what extent this happens, Brazilian official databases were accessed and with the aid of statistical software analyzed correlations between the number of cases of epidemic diseases such as Dengue, Chikungunya, Zika, and WSS infrastructures, particularly stormwater. The conclusion is that there is a convergence between the number of cases and the places with a deficiency of infrastructure or service provision. From this point of view, stormwater plays a considerable role. Furthermore, higher levels of GDP per capita, for example, do not indicate a lower presence of diseases.

### 9.1.7 Chapter 7

The chapter deals with the main aspect of the economic side of stormwater management service provision, the financial sustainability. Economic support through a widely used mechanism is the subject of a case study in this chapter: The Stormwater Utilities, which exist mainly in the USA and Canada, are analyzed in their particularities. The main calculation basis for charging is the sealed areas. In practice, two forms of economic support for drainage systems coexist, based on opposing views: the first is that stormwater is a general service and should therefore be borne by all taxpayers, maintaining the status quo in most places. The second view is that, according to the user-pays principle, only the users, including the public sector, should bear the costs of a service provided specifically to each one, in proportion to its use, represented, in principle, by the sealing of each lot. The additional advantage brought by this second understanding resides in the incentive given to reduce the waterproofing areas of lots, as happened in Munich, Germany. The conclusion reached is the feasibility of charging for the services, according to the user-pays principle, with the additional meaning of incentive to reduce the use of the existing systems and the burden on the environment and the receiving bodies, especially when it is possible to infiltrate or storage rainwater for use, aspects that are increasingly valued by society.

### 9.1.8 Chapter 8

The question to be answered in this chapter complements the previous one, in chapter seven, having as one of the objectives also to verify alternatives for financial support to the provision of urban stormwater services. The question is whether attracting Private Sector Participation (PSP) in stormwater sector is feasible or just a dream. The analysis starts from the need for the contribution of resources and the willingness of decision-makers to seek economic support outside the limits imposed on public budgets but within the constraints stipulated by the rules of the game (the institutions) and following existing policies and regulations. The research analyses some case studies. It concludes that the objective of attracting private capital requires solid strategies based on the vision of specific interests, public and private, following previously designed policies and not only considering the strategic objective of having more resources in cash or to compensate for budget problems. The conclusion regarding PSP in Brazil is that it still follows a logic that does not follow a PSP policy as a general strategy and explicit goals, discussed with the actors, but focuses only on solving specific issues, as is the case of reservoir maintenance in São Paulo, still in a sponsored concession logic, that is, with a strong contribution of public resources.  The privatization including concessions carried out in Brazil have in their design the figure of the initial rent, paid by the winners of bidding processes to the holders of the services, but without specifying the application of these resources. Such unbinding makes the PSP a mechanism for attracting resources unrelated to the object that motivates its use. The chapter conclude for the need to understand PSP as a way to make better the provision of services not only by the contribution of capital but by increasing management efficiency.

## 9.2 Limitations and future works

Every study is faced with barriers and limitations of various kinds and, therefore, it is always worth pointing them out so that it becomes clear that some aspects or issues constitute challenges to be overcome that can be embraced in future research.

### 9.2.1 Chapter 2

This hybrid literature review is successful in part because despite identifying that the topic is of growing interest in all countries it has not revealed any comparison of its effects or outcomes. This can be considered one of its major research limitations and an existing gap to be filled in future studies. The research process has obvious limitations due to the sample and existing papers in the database and the choice of words used in the search engine. The evidence shows that there are no articles dealing specifically with the subject, and when there are, the effects of PIR on the results are just superficially approached.  In addition to the effects on results, it matters to recognize not just the gaps in PIR, but the so-called Good Enough Governance, or trying to focus not just on the gaps, but on the issues that give better results and in the "how" and "how many times" it will take to obtain results with the few available resources in each country and context. The work shows that future research must focus on identifying PIR priorities, among many existing demands, to define goals, such as SDG6, providing contributions to reduce poverty and increase people's wellbeing. The study's attributions derive from the use of what exists in a single database, albeit ample (SCOPUS), from the natural exclusions by the choice and analysis software used, and even relative to the period in which it was researched (from 1980 until 2020) with the prevailing trends in each time and place, that is, in the time and space of the research carried out.

### 9.2.2 Chapter 3

When analyzing institutions in their relationship with policies and regulation in a PIR tripod, considered of fundamental importance for the study of governance in transition, that is, the paradigm shifts from traditional centralized drainage focused on command and control to sustainable, decentralized, and participatory stormwater, one faces limitations regarding the identification of actors and their importance in this transition. The fact is explained by the transition itself, in which two versions of governance coexist for some time, as institutions do not change as if by magic, suddenly moving from one position to the other. The same happens concerning the role of the actors who start exercising different functions at each stage of the transition. The difficulty in identifying the position at each moment of actors and institutions that, in each place, are subject to dynamics at different speeds is one of the limitations of the study. The reduced access to official documents that establish the determining actions of the changes, such as the determinations of the Chinese government regarding the institutions responsible for the actions contained in the Sponge Cities Initiative, is another example of the limiting factors of the study.

### 9.2.3 Chapter 4

The policy is a broad topic, but when it comes to policies that have urban stormwater as their sole and specific object, they are practically absent. However, when looking at more general policies, such as those related to the implementation of SDGs, we can notice their presence indirectly.  The difficulty in treating them theoretically is due not only to their complexity, as they involve multiple actors and disciplines, but also to the paradigm shifts in progress (from the traditional model to the sustainable one).

Thus, throughout this chapter, the limitations that have emerged are due to the identification of the separation between these two models, since the transition happens with the coexistence between the two models in the same space of time, when not in the same geographical space. The literature singly addresses them, as if they were a single model in transformation, when in fact they are two models that will coexist for a certain period. There are no quantitative results from the application of these models, only diagnoses of the situation of the systems, which brings limitations to a more robust theoretical analysis that would allow a comparison between them.

Thus, with the advance in the use of the new paradigm, their policies may be part of new studies that compare and quantify their performances, which will make new studies challenging.

### 9.2.4 Chapter 5

Chapter five addressed the regulatory issue of drainage in connection with the other two themes of the PIR tripod but presents as limitations the great absence of data because WSS regulation does not include urban stormwater, but also due to the low institutionalization of the sector and practically non-existent private participation in drainage.

In Brazil, considered in the infancy of regulation, the existence of only one regulatory agency for WSS services that has a more explicit approach to urban stormwater is an indicator of the low institutionalization of the sector. In the organizational structures, the theme is subordinated to others, like urban roadways, and does not have enough resources, and it is common to be assigned to agencies such as secretaries of work.  Future research may address the gaps related to the absence of regulation, formalized through contracts or agencies, verifying which quality or economic control instruments fulfill this role, especially when the provision is carried out directly by the titleholders themselves and what are the mechanisms used as incentives for better performance of stormwater systems from the standpoint of quality and economic efficiency.

### 9.2.5 Chapter 6

In this chapter, the study was motivated by the existing knowledge gap between WSS and health services, in Brazil placed in focus by the epidemics of DENGUE, CHIKUNGUNYA, and ZIKA, and in other countries by the pandemic of COVID-19.

The limitations, however, are related to the lack of accessible data, with a higher level of disaggregation, especially when it relates to the infrastructure of the municipalities, and we can specifically mention the information on the presence of household reservoirs or infrastructure and areas inhabited by populations considered vulnerable, such as slums. Census data are still stationed more than ten years ago, in 2010, when the last national census took place. The simultaneous occurrence of diseases with similar symptoms, as is the case, for example, of Dengue and COVID-19, is a limitation to the accuracy of diagnoses and data.

It should be remembered that the establishment of public policies in the absence of correct information implies significant potential inefficiency, the same occurring concerning future research.

### 9.2.6 Chapter 7

The last two chapters address economic aspects related to the organization and economic sustainability of urban stormwater services. In this chapter, the seventh chapter, through some case studies in cities where it was possible to enable the collection of fees through the use of several calculation methods that estimate the sealed areas and the contribution shares of each lot to the systems, it was possible to analyze how this works.The limitations, however, are due to the lack of a larger number of examples that would allow a greater comparison between the different charging systems and the difficulties in implementing them.

In the studies to which we had access, there is no more detailed quantitative information about collections, default rates, or even the application of the funds collected, which we understand may be the subject of future research to allow us to assess the economic and financial performance of the alternatives.

### 9.2.7 Chapter 8

Finally, in chapter 8, which also deals with economic issues related to the organization and economic support of stormwater systems, focusing on PSP, the limitations of the study are related to the absence of detailed information on cost aspects, which, when not absent, are aggregated and do not allow for the quantification of aspects of interest to PSP to be visualized in a segregated way. This is valid both for the quantification of precipitated, infiltrated, evaporated, and drained volumes, and for the operation and maintenance costs of existing systems in operation. Except for a study on Sponge Cities Initiative, there is also no data available on the willingness to pay of the population in each location, and relevant information to understand the political and economic carrying capacity of society. All these aspects are reasons for further studies.

# 10. RECOMMENDATIONS

## 10.1 Introduction

Although they are all interconnected, actions which contribute to one of the SDG targets may also have a positive or negative impact on other of the 17 Goals and targets. Considering that the SDG's are goals that permeate the recommendations resulting from this study, those goals and targets that are perceived to fit more strongly are cited in each recommendation. After the recommendations, a list with the cited goals and targets (T) is included in order to facilitate reading and understanding the links between the recommendations and the SDGs and their targets (T).

## 10.2 The recommendations are:

1. Encourage the implementation of policies and actions that contribute to a change in mentality regarding the use of urban stormwater as a resource and not as a problem, favoring its use (e.g., by collecting rainwater and storing it for use as toilet flushing and garden watering or after treating as potable use). This change of mentality covers all aspects of the transition from traditional to sustainable paradigms as pointed out throughout the text and are also present in the recommendations suggested below.

2. Development of Stormwater Management Policies with explicit objectives, regarding quantitative aspects, such as the reduction of floodable areas, vulnerable areas, areas with no or intermittent water supply or insufficient infrastructure for wastewater and stormwater drainage, contemplating goals over time. The same applies to the qualitative aspects of pollution reduction in receiving bodies and treatment of rainwater effluents (stormwater). These policies should consider population growth and estimated migration movements, in addition to aging infrastructure and demands related to climate change (T 13.2) aiming at building disaster resilient environments such as floods (T 1.5).

3. Elaboration of financing policies that provide resources for municipal structuring and allow for the needs of existing infrastructure (maintenance and operation) and the expansion of necessary but non-existent ones (construction and implementation). Such policies should consider the involvement of the various actors, especially considering the polluter-pays principle, materialized by the impermeable area of the lots ($m^2$), whether public or private, without neglecting to consider, where necessary, the application of subsidies or discounts (T 10.4). The consideration of the possibilities of attracting the participation of private initiative through known mechanisms, such as PPP's (T 17.17) and stormwater utilities, equity participation, and even privatization, or mechanisms that may be created, should not be ignored when designing policies aimed at building financial support and efficiency gains (T 17.1).

4. Develop policies to combat stormwater-related diseases and improve information campaigns on the link between stormwater and the presence of vectors, e.g. Aedes Aegyptus (T's 3.3, 3.b and 3.d). Carry out the quantification of health costs as an effect of the non-

existent or intermittent functioning of drainage infrastructure and its inter-relationships with other urban water systems. The latter, although not an easy task, should be pursued as a measure that aims to obtain quantitative data of the positive effects on related areas such as health, allowing the quantification of these indirect effects, their accounting in the results, budgets and decision making better grounded in reality.

5. Inclusion in the databases of information relative to drainage infrastructure and its management, in a disaggregated manner, by neighborhoods (T 17.18). Such disaggregation does not occur, for example, in the Brazilian database, the SNIS. Without this data, it is impossible to elaborate policies with targeted goals and the inclusion of peripheral neighborhoods and slums (T 11.1 and T 17.15), i.e., covering the entire population.

6. Build and increase mechanisms that enable the democratic participation of all sectors of society, since the universalization of solutions in the territories requires staggered actions and these depend on consensus among interests that are not always identical. Governance, as well as institutions, built to face this challenge, must also meet the support of all (T's 16.6 and 16.7).

7. Set in motion the execution of stormwater policies that address the SDGs, particularly those aspects most closely connected with urban drainage systems (SDGs 1,3,6,10,11,12,13,16 and 17) considering ways to measure the achievement of achievable goals (T 17.19).

8. Involve those sectors of society that can make applicable theoretical and practical contributions, such as Academia, professional and business institutions (e.g. CIRIA in the UK, Ordem dos Engenheiros in Portugal, ABNT and CREA in Brazil) and regulatory bodies. Such involvement should pay attention to new techniques and alternatives (such as infiltration of runoff through green and porous spaces, like roofs and sidewalks), and produce carefully elaborate standards. Similarly, attention should be given to technical solutions that, under the apparent argument of evolution, in practice mean retrogression, as is the case of alternatives proposed in Rio de Janeiro, called "dry weather drainage", which are nothing more than the release of wastewater, without treatment, in stormwater networks, i.e., contrary to established best practices (networks was previously designed and built to operate as separator networks), which means a technical retrogression.

9. Establish public and private regulation (T 10.5) based on an efficiency mindset founded on the pursuit of pre-established and measurable results. The absence of expected and established results from the design onwards during construction, operation and management of urban stormwater systems (SDG6) should be a deterrent to financing actions. Simultaneously establish public and private regulation with a focus on the efficient use of resources, considering stormwater as such within the urban water cycle, appropriating its value according to its uses and quality. On this way, aquifers recharge by stormwater must be considered in attention to scarcity and environment.

10. Consider pilot projects, in progress, as is the case of China, where experiments are being conducted in 30 cities, and others to be built in different climates, but with a focus on previously defined results to be measured during their useful life. Establish a network for

exchanging experiences and experiment results, with a database of broad access, in order to rapidly evolve the technology of the sector (T 17.7), contributing to face the changes that lie ahead.

11. Implement policies for public projects that consider the use of rainwater in buildings and urbanistic actions, in order to disseminate the idea that rainwater is an urban resource, part of the environment, and should be seen as such in all projects and actions (T 11.1). Also implement policies to complement incomplete or insufficient urban infrastructure, as occurs in the urban bangs and slums and other parts of urban territories, with preference for implementation in places where water scarcity and the incidence of diseases related to sanitation is more pronounced, according to infrastructure and health indicators. The supply of these sanitation infrastructures must consider that it is necessary to overcome the issue of legal or non-legal ownership of the lots and use technologies and techniques that do not always obey traditional standards, that is, the implementation must consider all possible alternatives according to their costs and forms of subsidies where necessary (T 11.3).

12. Disclose in all actions related to stormwater, information regarding the objectives and reasons for each one, in order to create the custom that these actions, whether public or private, deserve to have their disclosure made and received by society as a mandatory feature necessary to life in common, stimulating social participation. Developing communication channels and tools to accomplish this goal in a simple and didactic way to everyone, whether technicians or just citizens. This disclosure allows the monitoring and accountability regarding the achievement of goals and objectives by society (T 1.4).

13. Consider, always explaining to the actors, that for a long time the solutions built under the two optics, that is, traditional drainage and sustainable stormwater management, must coexist, requiring that governance be done taking into account the combination of systems with different conceptions, but that they must continue to coexist in the most harmonious way possible, optimizing the investments already made. The paradigm shift requires transition periods and these, like the institutions, may be different in each location.

14. Align the incentives produced by policies, institutions and regulation in a way that maximizes the effects of the former to achieve results. Policies for the use of stormwater as a resource require institutions that make them feasible (such as legislation regarding taxes and incentives for retention and use on the lot or their disconnection from public sewage systems), but at the same time also aligning regulation to calibrate the size of taxes and subsidies in order to obtain the desired results. The institution of incentives for disconnection, for example, should be regulated so as not to reach a level where existing systems become idle and thus economically unviable (T 10.5).

15. Establish tariff structures that encourage the use of stormwater as a resource but also promote understanding of the function of stormwater infrastructure like means to the public services provision that must receive economic support from all. Charging should preferably be decided with the widest participation of society and included, where possible, in the bills for sanitation services, indicating in a didactic way this fact and thus contributing to the dissemination of the understanding that this is a public service related to urban sanitation, for

which everyone has responsibility. Also this tariffs structures must provide means to reduce the bills, e.g. by reducing tariffs for whom make actions to reduce the stormwater flows and pollution, in this way incentivizing active participation and not just passively paying of the bills.

16. Incorporate the treatment of rainwater, within the mentality that it is a resource, aiming at its use as close to the source as possible, i.e. in places of precipitation, where there is the expectation that its quality is better (before runoff) and also with the possibility of aquifers recharge. Also, favor the implementation of green infrastructures with the focus in quality and quantity of stormwater (T 11.7).

17. Attract, on the demand side, the stormwater consumer's use and on the supply side the private capital so that its economic and socio-environmental viability grows and there is a greater incorporation into the urban water cycle, enabling its visualization and the expansion of its multiple uses, combating scarcity (T 6.4), the urban heat islands and providing an increase in user's and in the number of available cities water amenities.

18. Broaden the mindset that rainwater is a manageable resource in the face of climate change (T 11.B) and that it can contribute to reducing its impacts (T 11.5) by having predictable structures built for storage, mitigation, use, treatment, and utilization (T’s 12.8 and 13.1), anticipating and avoiding expenses, which occur today in unpredictable ways, negatively impacting not only the physical and social environment, but also public and private budgets.

19. Design the transition and coexistence between traditional urban drainage structures and sustainable devices according to the new gray-green infrastructures paradigm, thinking about sustainability, joint maintenance and operation and applying new technologies, e.g., internet of things (IoT) to manage the systems (T 17.7).

### 10.3 SDG’S and Targets understood as directly linked to stormwater management:

SDG 1 – End poverty in all its forms everywhere.

Target 1.4. By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance.

Target 1.5. By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters.

SDG 3 – Ensure healthy lives and promote well-being for all at all ages.

Target 3.3. By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases.

Target 3.B. Support the research and development of vaccines and medicines for the communicable and non-communicable diseases that primarily affect developing countries, provide access to affordable essential medicines and vaccines, in accordance with the Doha Declaration on the TRIPS Agreement and Public Health, which affirms the right of developing countries to use to the full the provisions in the Agreement on Trade-Related Aspects of Intellectual Property Rights regarding flexibilities to protect public health, and, in particular, provide access to medicines for all.

Target 3.D. Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks.

SDG 6 – Ensure availability and sustainable management of water and sanitation for all.

Target 6.4. By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.

SDG 10 – Reduce inequality within and among countries.

Target 10.4. Adopt policies, especially fiscal, wage and social protection policies, and progressively achieve greater equality.

Target 10.5. Improve regulation and monitoring of global financial markets and institutions and strengthen implementation of such regulations.

SDG 11 – Make cities and human settlements inclusive, safe, resilient and sustainable.

Target 11.1. By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums.

Target 11.3. By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.

Target 11.5 By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.

Target 11.7 By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, particularly for women and children, older persons and persons with disabilities.

Target 11.b. By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels.

SDG 12 – Ensure sustainable consumption and production patterns.

Target 12.8. By 2030, substantially reduce waste generation trough prevention, reduction, recycling, and reuse.

SDG 13 – Take urgent action to combat climate change and its impacts.

Target 13.1 Strengthen resilience and adaptive capacity to climate related hazards and natural disasters in all countries.

Target 13.2. Integrate climate change measures into national policies, strategies and planning.

SDG 16 – Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.

Target 16.6. Develop effective, accountable and transparent institutions at all levels.

Target 16.7. Ensure responsive, inclusive, participatory and representative decision-making at all levels.

SDG 17 – Strengthen the means of implementation and revitalize the global partnership for sustainable development.

Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development.

Target 17.1. Strengthen domestic resource mobilization, including through international support to developing countries, to improve domestic capacity for tax and other revenue collection.

Target 17.7. Promote the development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries on favorable terms, including on concessional and preferential terms, as mutually agreed.

Target 17.15. Respect each country's policy space and leadership to establish and implement policies for poverty eradication and sustainable development.

Target 17.17. Encourage and promote effective public, public-private, and civil society partnerships, building on the experience and resourcing strategies of partnerships.

Target 17.18. By 2020, enhance capacity-building support to developing countries, including for least developed countries and small island developing States, to increase significantly the availability of high-quality, timely and reliable data disaggregated by income, gender, age, race, ethnicity, migratory status, disability, geographic location and other characteristics relevant in national contexts.

Target 17.19 By 2030, build on existing initiatives to develop measurements of progress on sustainable development that complement GDP, and support statistical capacity building in developing countries.

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A.

# APPENDIX

# A Appendix to Chapter 2 – Scopus search codes

Table 0.1A - Search Codes

| number | Scopus search codes |
|---|---|
| 1 | TITLE-ABS-KEY (polic* AND Institut* AND regulat* AND drainage) AND (LIMIT- OCTYPE,” ar”) OR LIMIT-TO (DOCTYPE,” re”)) AND (LIMIT-TO (SUBJAREA,” ENVI”) OR LIMIT-TO (SUBJAREA,” SOCI”) OR LIMIT-TO (SUBJAREA,” ENGI”) OR LIMIT- (SUBJAREA,” BUSI”)) AND (LIMIT-TO (LANGUAGE,” English”)) AND (LIMIT-TO (SRCTYPE,” j”)) |
| 2 | E-ABS-KEY(polic* institut* regulat* stormwater) AND ( LIMIT-TO ( DOCTYPE,"ar" ) ) AND ( LIMIT- UBJAREA,"ENVI" ) OR LIMIT-TO ( SUBJAREA,"ENER" ) OR LIMIT-TO ( SUBJAREA,"SOCI" ) OR LIMIT-TO ( SUBJAREA,"BUSI" ) OR LIMIT-TO ( SUBJAREA,"ENGI" ) ) |
| 3 | TITLE-ABS-KEY (polic* AND institut* AND regulat* AND rainwater) AND (LIMIT-TO (DOCTYPE,” ar”) OR LIMIT-TO (DOCTYPE,” re" ) ) AND ( LIMIT-TO ( SUBJAREA , "ENVI" ) OR LIMIT-TO ( SUBJAREA , "SOCI" ) OR LIMIT-TO ( SUBJAREA , "BUSI" ) OR LIMIT-TO ( SUBJAREA , "ENGI" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) OR LIMIT-TO ( LANGUAGE , "Spanish" ) ) AND ( LIMIT-TO ( SRCTYPE , "j" ) ) |
| 4 | LE-ABS-KEY (polic* AND regulat* AND rainwater) AND (LIMIT-TO (SRCTYPE,” j”)) AND (LIMIT-TO (DOCTYPE, ”ar" ) OR LIMIT-TO ( DOCTYPE , "re" ) ) AND ( LIMIT-TO ( SUBJAREA , "ENVI" ) OR LIMIT-TO ( SUBJAREA , "SOCI" ) OR LIMIT-TO ( SUBJAREA , "BUSI" ) OR LIMIT-TO ( SUBJAREA , "ENGI" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) OR LIMIT-TO ( LANGUAGE , "Spanish" ) ) |
| 5 | -ABS-KEY (polic* AND regulat* AND stormwater) AND (LIMIT-TO (SRCTYPE,” j" ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO ( DOCTYPE , "re" ) ) AND ( LIMIT-TO ( SUBJAREA , "ENVI" ) OR LIMIT-TO ( SUBJAREA , "SOCI" ) OR LIMIT-TO ( SUBJAREA , "BUSI" ) OR LIMIT-TO ( SUBJAREA , "ENGI" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) OR LIMIT-TO ( LANGUAGE , "Spanish" ) ) |
| 6 | LE-ABS-KEY (polic* AND regulat* AND drainage) AND (LIMIT-TO (SRCTYPE,” j”)) AND (LIMIT-TO (DOCTYPE,” ar" ) OR LIMIT-TO ( DOCTYPE , "re" ) ) AND ( LIMIT-TO ( SUBJAREA , "ENVI" ) OR LIMIT-TO ( SUBJAREA , "SOCI" ) OR LIMIT-TO ( SUBJAREA , "BUSI" ) OR LIMIT-TO ( SUBJAREA , "ENGI" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) OR LIMIT-TO ( LANGUAGE , "Spanish" ) ) |
| 7 | -ABS-KEY (institut* AND regulat* AND drainage) AND (LIMIT-TO (SRCTYPE,” j" ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO ( DOCTYPE , "re" ) ) AND ( LIMIT-TO ( SUBJAREA , "ENVI" ) OR LIMIT-TO ( SUBJAREA , "SOCI" ) OR LIMIT-TO ( SUBJAREA , "BUSI" ) OR LIMIT-TO ( SUBJAREA , "ENGI" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) OR LIMIT-TO ( LANGUAGE , "Spanish" ) ) |
| 8 | TITLE-ABS-KEY (institut* AND regulat* AND stormwater) AND (LIMIT-TO (SRCTYPE,” j" ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO ( DOCTYPE , "re" ) ) AND ( LIMIT-TO ( SUBJAREA , "ENVI" ) OR LIMIT-TO ( SUBJAREA , "SOCI" ) OR LIMIT-TO ( SUBJAREA , "BUSI" ) OR LIMIT-TO ( SUBJAREA , "ENGI" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) OR LIMIT-TO ( LANGUAGE , "Spanish" ) ) |
| 9 | -ABS-KEY (institut* AND regulat* AND rainwater) AND (LIMIT-TO (SRCTYPE,” j" ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO ( DOCTYPE , "re" ) ) AND ( LIMIT-TO ( SUBJAREA , "ENVI" ) OR LIMIT-TO ( SUBJAREA , "SOCI" ) OR LIMIT-TO ( SUBJAREA , "BUSI" ) OR LIMIT-TO ( SUBJAREA , "ENGI" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) OR LIMIT-TO ( LANGUAGE , "Spanish" ) ) |

A. 4

A. 4

# B Appendix to Chapter 4 – Article Water Science & Technology 2022

Water Science & Technology Vol 85 No 9, 2652 doi: 10.2166/wst.2022.127

Public policy: urban stormwater in a paradigm shift, is it the end or just the beginning?

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ABSTRACT

The perception that urban stormwater policies are non-existent, incomplete, or lacking in aspects that concern the environment and quality of life in cities has become increasingly common. This is partly due to the increased frequency and magnitude of rainfall events resulting from climate change and its economic, social, and environmental consequences. Population concentration and changes in patterns of living, construction, and urbanization contribute to the pollution of water runoff and receiving waters. Thus, quantity and quality problems add up and often require costly solutions, which are then addressed as economic issues. To deal with all these aspects, many of which were previously absent, stormwater public policies require a paradigm shift to break away from institutional inertia and dependence on the previous path. Without the aim of exhausting the subject, this paper discusses the policy aspects that concern stormwater management and the current and desired paradigm shift.

Key words: city management, public policy, stormwater management, urban drainage, urban water



HIGHLIGHT

Urban stormwater issues are highly complex as they involve many actors, conflicting interests, difficult to predict future trajectories and causes that are fuelled by consequences. Public policies addressing complex issues are the result of decisions reached by consensus, but not unanimity, among stakeholders and, as institutions, are path dependent and decisive for the outcomes to be achieved.

## 1. INTRODUCTION

Decisions made by governments are materialized through public policies that direct actions to achieve certain pre-defined objectives. Policies can be created and implemented through different instruments such as laws and regulations, specific actions, or even funding priorities. Policies can be responsible for leveraging incentives for sustainable service delivery and for enhancing and transforming the existing institutional and regulatory framework (Mumssen et al. 2018).

There are many interpretations of the word policy and one of them is a definition, according to Hill's review of the term (Hill & Varone 2021), present in the Oxford English Dictionary, 2nd ed. of 1989: 'A course of action adopted and pursued by a government, party, ruler statesman, etc.' In this sense, for example, Water Sensitive Urban Design (WSUD), is a water policy adopted and purposed by governments and professional institutions in Australia.

Public policies have two fundamental aspects: their formulation and their evaluation after application, which is the third and intermediate aspect, between the other two. The implementation stage has as determinants the organizational and political conditions, that is, the political and the associated social costs within a governance structure and economic policy of the sector where, for example, some actions may have difficulties of political and public support for their implementation, despite being efficient (Mumssen et al. 2018). Several factors can inhibit policy implementation such as lack of qualified personnel, lack of leadership, opposition, corruption, and many others.

This article aims to present an overview of urban stormwater management policies as they relate to institutions and regulation, but with a special focus on the paradigm shift underway (Dhakal & Chevalier 2016) in several aspects that the complexity of the subject requires. Urban stormwater management is a complex issue, i.e., it involves multiple actors, is inter-disciplinary, does not allow for accurate predictions as to its future course, and has consequences that feedback into its causes. The ongoing paradigm shift takes place about most of the aspects involved such as: technological, environmental, economic, social, political, legal, and institutional (Furigo 2020). In technological terms, the perception that quantitative control, or control of volumes associated with precipitation, can be better carried out at the source and not at the end of the runoff makes it possible to resort to smaller and more cost-effective solutions, not excluding the simultaneous 'end of the pipe' treatment, but which has a different conception. As for the issue of runoff quality, or in terms of contamination, previously considered practically non-existent, which concerns the environmental aspect, imbricated with the technical solutions, there are treatment alternatives (Chouli 2006) also at the source or along with the runoff, but before the outlet, through techniques called alternatives, favoring the infiltration and evapotranspiration, as in detention basins, retention, bio-drainage ponds, porous pavements, and other alternatives. In the economic aspect, the present reflection is on the alternatives for obtaining resources and financing for the construction, operation, and maintenance of infrastructure systems. Questions about the best way to obtain resources, whether from users (Zhao et al. 2019), taxpayers or through creative solutions such as public–private partnerships (PPPs) or other forms that are legally and politically acceptable to society, and the absence of specific sources of funding for the activity, as is the case in most countries nowadays, transforms its funding into an aspect of change (Veiga et al. 2021), the same occurring with the institutional, organizational and management structures, including the structure of personnel and their training for the activity. In a simultaneous movement with the actors involved and their diverse interests, all these aspects require organizational and institutional structures subject to distributed governance, that is, with the democratic participation of the actors aimed at reaching consensual solutions.

Various aspects are being questioned such as the costs of alternative solutions in the face of budget restrictions, which on the one hand present barriers to their construction, but on the other hand present opportunities for change towards other ways of obtaining resources and financing systems and management structures with the participation of other stakeholders, including users or investors or those who for any reason have an interest in participating in projects and actions related to urban stormwater.

The methodology used is based on a narrative constructed from the bibliography available through research in databases such as Scopus, but also in various other means available, in networks and other sources of documents. The text was based on research, experience, and reflection and took into consideration the existing recent papers available in the literature accessed relying, therefore, on the international experience built over the last decades.

The main contribution of this research lies in the effort to systematize relevant issues around the subject of urban storm-water from a public policy perspective, which in practice are almost totally absent in most countries, regardless of their stage of development and their technical, socio-economic, and cultural context. For several reasons, this absence, materialized by the limited capacity to respond to rainfall events across the globe (Kondratenko et al. 2021), has caused concern among scholars and the public, for whom we hope to provide useful contributions

The results obtained with existing policies or their absence are reflected in the fragile conditions presented by cities about rainfall events that invariably, whether in developed or developing countries, resulting in disruption and material and human losses. There are no ready formulas for dealing with stormwater runoff, but in each place, the structures in charge of these tasks deserve to be built, where they do not exist, or rethought in the light of new demands arising from the confluence of old and new events such as accelerated urbanization and climate change. All these elements have required changes in the way urban stormwater is treated, which we call a paradigm shift (Bertrand-Krajewski 2021). This change has already been occurring to varying degrees depending on the specific economic and social characteristics of each location with varying results, but with little impact on the specialist literature, reflecting the incipient discussion of this issue in academia or the lack of transparency of the discussions.

This article is structured in four sections in addition to this brief introduction. Section 2 deals with public policies including the Sustainable Development Goals (SDGs). Section 3 addresses the drainage policies emphasizing its financing. Section 4 discusses the results obtained and, finally, section 5 presents the concluding remarks.

## 2. PUBLIC POLICIES

### 2.1. Background

Public policies are always choices in a framework of preference conflicts, mediated by inclusive political institutions to a greater or lesser degree, which reflect the degree of influence of different actors in the decision-making process (Sarti et al. 2018).

Thus, public policies, as a result of political decisions established in political processes characterized by the existence of different, and often conflicting conceptions (in terms of values and ideas) about the role of the state and its degree of intervention in society, are built not always from real problems, but from the understanding by political actors, both governmental and non-governmental, of what are problems or problematic situations that deserve to be part of a government agenda through a particular public policy.

Water and sanitation whose main function is the prevention and promotion of health refer to public policies related to health (Sarti et al. 2018), which is different from the classic policies of service provision as market goods. Since water and sanitation are not separated from health policies, intersectionality between these policies is necessary. However, this is not always the reality observed, which leads to a limited approach to health policies.

Changes in certain policies depend, however, on conjunctures, invariably provided by crises in which there are institutional imbalances favorable to change or opportunities for political transformations such as changes in government, economic changes, and others.

Additionally, from the perspective of the new institutionalism approach, in which institutions play a decisive role in policy outcomes, the alternatives of available policy choices are conditioned by the institutional effects of previous choices, that is, conditioned by past policies that established different actors and institutionalized certain practices and rules, configuring a relation of path dependence with the State as the structuring agent.

Public policies are also important rules of the game and, therefore, can be included in the list of institutions, and lead to the constitution of organizations and other institutions to enable their implementation.

In societies under democratic regimes, in which power alternates, water and sanitation public policies, including in long-term planning, are State policies and not just government policies, since the latter is transitory.

### 2.2. Sustainable development goals – SDG’s policies

Water and sanitation as a right, recognized by the United Nations (UN) General Assembly (Resolution 64/292) and the Human Rights Council (Resolution 15/9) in 2010, refers to universal access to the related services and, therefore, the need for policies that consider, where not achieved yet, the issue of access to all in an equitable way. Universalization encompasses the inclusion of all water and sanitation services, non-intermittent and quality water supply, and comprehensive, including, when possible, fair tariffs established in a way that does not constitute an obstacle to universal provision (Neto & Camkin 2020).

In 2015, all UN Member States adopted the 2030 Agenda for Sustainable Development, including a goal (SDG6), with the main objective of ensuring the availability and the sustainable management of water and sanitation for all, but unless current rates of progress increase substantially, targets will not be met by 2030.

Thus, in 2020, according to UN, even though handwashing is one of the cheapest, easiest, and most effective ways to pre-vent the spread of diseases, and also coronavirus an estimated 3 billion people worldwide could not wash their hands at home. However, nothing is said about rainwater, which is absent from the statistics and therefore from the analysis, even though it can be considered an important resource in solving the urban scarcity and other questions.

The level of water stress (SDG6.4.2 target), characterized by greater consumption of water from natural sources, is a phenomenon that occurs in most regions of the world. Urban consumption, besides trying to be more efficient, can have policies which improve the control of losses in the networks, use rainwater for non-potable uses, and also reuse the water used.

A recent World Bank study estimates that meeting the sixth of the SDGs could cost USD116 billion per year through 2030. These costs unbundle into the separate costs of providing safe water (USD37.6 billion per year), safe sanitation (USD19.5 billion per year), safe fecal waste management (USD49 billion per year), and hygiene facilities and education (USD2 billion per year) (Staddon et al. 2020). These costs are, however, minor compared to the costs necessary to get the economy going again in the post-pandemic period and may be smaller if rainwater is considered as a resource.

About SDG 11.3.1 and urban planning, given the expected increase in rainfall, studies in Hamilton, near Toronto, Canada, have found that population growth is higher than the increase in land use, which is a good indicator for urban stormwater management (Philip 2021).

2.3. Policies for the universalization of services

The biggest challenges for the universal access to water and sanitation services are the rural areas and the peripheral areas of the cities, including the big cities, such as São Paulo in Brazil, where the issue of water security is very sensitive to several conditions such as social inequalities, environmental and climatic conditions, political processes and past events.

São Paulo, compared to London in the UK, despite their differences and similarities, brought to light, during the event of the COVID-19 pandemic, the risks to which both populations are permanently subjected, especially the poorest and most vulnerable, and the importance of policies focusing on water security. There are several vulnerabilities, such as insufficient water reservoirs, inequalities in access to and use of water, overcrowded housing, and lack of shelter for many (Alves et al. 2021).

During the pandemic of COVID-19, at the same time as water scarcity for handwashing occurs, flooding events occurred in 70 countries (Simonovic et al. 2021). While the pandemic requires isolation and social distancing, flooding events require or entail, on many occasions, proximity between people, making the goals contradictory for given moments. This reality makes it necessary to think about policies that consider the possible occurrence of multiple simultaneous adverse events (e.g., pandemic and water scarcity or excess). This can be taken into account through scenario simulations considering the concept of dynamic resilience, i.e., in which actions may be modified according to the evolution of events. This possibility is unusual among decision-makers who need to adapt to the concept of dynamic resilience by receiving information in advance so that they can formulate policies and plan actions, i.e., that include the greatest possible resilience of existing systems, which requires a change in thinking from static to dynamic resilience and from one adverse event to multiple simultaneous adverse events.

The implementation of policies aimed at the use of rainwater, within the logic of the urban water cycle, in the same way that the conscious use of groundwater which can even count on receiving contributions from rainwater, deserves to be encouraged, not only for the potential of facing the urban water shortage and, therefore, not only to meet the proposed in SDG6, but also to combat situations of vulnerability to diseases, especially those related to floods.

Urban rainwater certainly has an important role to play in combating situations of scarcity or excess in cities, but to do so it needs to have adequate management policies that are integrated with health, housing, and territorial and infrastructural planning policies.

## 3. DRAINAGE POLICIES

### 3.1. Drainage policies in a nutshell

Drainage policies, except for in the USA, whose existence dates back to 1987 with the Clean Water Act (CWA), and in Australia, where the Australian Drinking Water Guidelines exist since 1996 (Fletcher et al. 2015), do not have a long history. In Europe, drainage has recently received more attention; however, in other countries, such as Brazil, it is almost imperceptible (Montenegro 2017). In China, with the recent greater development of cities, since 2015 there is a growing concern and the establishment of a national policy under the title of Sponge Cities (Yin et al. 2021).

Another aspect that influences the structuring of policies in the sector concerns the more general political structures, federalist, democratic and distributed, as in the USA, or like China, with centralized political power. The legislation also follows this logic, with each country, state, municipality, district, county, or consortium and other forms of a grouping of federative entities having specific rules and ways to obtain different resources. It is important to note that stormwater does not follow the logic of administrative divisions and subdivisions, but rather that of hydrographic basins or hydrographic regions, containing several basins, as is the case in Portugal (Arezes et al. 2019).

The logic of analysis by watersheds, however, is not exhausted in itself and leads us to think about natural and built territories, and thus, about the planning of their use and occupation, that is, about territorial planning as a basis. The territory is the space where planned actions take place as a result of negotiations and political interactions between the various actors present or with interests that occur in the territory. Through collective decisions, the municipalities seek to ensure quantity with quality, prevent floods and mitigate droughts, without pushing problems from one municipality to another.

Urban water management is subject to the interaction of numerous public interest groups, private or otherwise, which have contradictory and conflicting behaviors, but without them, it is difficult to obtain solutions that derive from shared decisions whose main objectives are flood and pollution control. Each optimal solution chosen represents the best possible compromise between the various interests at a given moment.

In this perspective of participation, it is in the territories, spaces where the actions take place, that the urbanistic projects, new or of urban requalification, respond to the interests of certain social groups and illustrate the political priorities (water saving, economic growth, health security, better standard of living, and environmental quality) that determine the decisions and choices made and to be made. This has been the case since the nineteenth century, a time when water and sanitation infrastructure was seen as a sign of modernity and urban comfort. However, since then, such technical superiority has foundations and arguments of socio-political order having been, for example, the Parisian option for what became known as 'tout-à-l'égout', a strategic political decision in which the State assumed responsibility for the water evacuation and treatment, because Paris, being an important capital, could not have its image damaged by the ways of handling water and sanitation as the transportation of sewage through the streets (Chouli 2006).

Urban hydrology, which had hygiene as its philosophical and theoretical foundation, is today a hybrid science involving physical phenomena, technical problems, urban society, and public policies and as such is in permanent evolution, not only in its technical and innovative aspects but because it has to consider socio-economic and environmental conditions.

Decisions within a preference system are made as a result of negotiations and depend on the existing players and available information. Thus, the decision process itself may influence the decision made, such as, for instance, depending on the players who may propose, through an environmental institution, that environmental impact studies be considered or, for instance, if the technicians only present solutions based on channeling, other alternatives are discarded even though they are based on better accepted public policies, such as those that aim at water-saving, controlling urban rainwater runoff at the source and avoid the significant use of channeling.

The instruments used by actors to implement a public policy are represented by all activities, decisions, and measures aimed at solving a certain problem (laws, working methods, information campaigns, assignments of roles and powers, decisions to include different actors, or the choice of a management model). These instruments are characterized by their objectives and for urban stormwater management they can be classified into three types: command and control (legislation and regulation); fiscal incentive policies (runoff charges based on impermeable m²) and technical expertise, information, and public awareness, but one type of instrument may achieve several objectives at the same time (Chouli 2006).

Stormwater management in Europe can be described as a combination of four variables: direct or delegated management, management at the national, regional, or local level, management by the public or private sector, and management with or without partnerships, for example, direct management by the municipality or by a private company delegated by the central state or managed through a public partnership between local authorities and many other forms.

Alternative techniques, under the principle of decentralization and control of stormwater pollution at source, require new decision-making processes based on multidisciplinary collaboration, consensus between different actors and different institutional, organizational structures, political (legal, economic, and socio-political) enforcement instruments. It is the legislation that creates the obligations to establish means including the installation of treatment plants or results such as the reduction of the concentrations of specific pollutants in the receiving bodies.

The European directives, e.g., Water Framework Directive (WFD) 2000/60/EC and the Directive 2007/60/CE, also known as the Floods Directive (FD), which has as its main objective the establishment of a general framework for the assessment and management of flood risks, do not focus on stormwater.

Initially, the WFD focused on the mitigation of pollution sources, such as agriculture, industry, effluent treatment plants, overflows from combined systems, and direct sewage discharges into receiving water bodies. Without paying attention to separate systems, especially stormwater discharges, disregarding its quality, considered until then as not a major problem, neither the WFD nor the FD use the term 'stormwater'. WFD only mentions the word 'drainage' about the classification of surface waters as artificial or strongly impacted and when dealing with the contamination of groundwater by artificial recharge anthropogenically altered by rainwater runoff drainage. And finally, the word 'precipitation' is used in the WFD only to describe characteristics of rivers and FD never uses these words (Jensen et al. 2020).

Thus, an important policy change would be to not only adopt the terms but to consider the effects of the separate systems so that in Europe all impacts on the receiving bodies would be considered, aiming at total pollution control, which does not occur by leaving aside the stormwater separate system.

In Europe, concerning the technology and investment priorities associated with water management in cities, the first priority is related to the storage of water supply. The second is wastewater treatment, especially for sanitary reasons and to maintain the quality of receiving water bodies (lakes and rivers), often also used as a source of water resources, as is the case of rivers in France, Germany, the United Kingdom, and the Netherlands. Finally, the third priority refers to diffuse pollution that originates from two main sources: urban runoff and agriculture, the latter due to the use of pesticides and fertilizers.

In Portugal, there are references to stormwater in the Regulatory Decree No. 23/95, but stormwater drainage lacks specific regulation. However, the General Drainage Plan of Lisbon – PGDL 2016–2030, is a municipal strategic document that has as its political objective the preparation of the city for the future, mitigating the consequences of climate change expressed by significant and increasingly frequent rainfall events. One of the principles of this plan is the flow control at the source through the construction of retention and infiltration basins and drainage trenches, in addition to tunnels, pavements, and other interventions, amounting to a total value of 250M€ (Béraud et al. 2021).

Urban runoff, however, presents different problems when there are combined or separate systems, the former being more important in controlling overflows in rainy periods. This latter problem can be solved by the construction of separate systems and disconnection of stormwater from the combined system or by expanding sewers and treatment plants. In the case of separate systems, polluted effluent is also received in stormwater networks, especially in rainy periods due to the first flush, but also in dry periods due to illegal or poorly constructed wastewater connections and infiltration. Each situation presented requires specific policies for its solution. Additionally, a priority that runs parallel to the other three is flood protection.

3.2. Funding and financing policies

In Europe, the importance of urban stormwater management and, therefore, stormwater policies, increases over time, correlates with other technical priorities related to water quality, and can also be understood as the sum of the importance of flood protection and urban water quality. Such priorities, in each municipality, are influenced by local contexts and by national and regional policies, as well as by European Union policies.

Public policy funding actions refer to the real or perceived needs of coalitions of actors, especially those in power, and thus the funding of drainage systems requires them to be perceived as important by actors, especially decision-makers and society in general.

Water policies in cities have always focused mainly on water supply and wastewater, leaving rainwater in the background and, consequently, also the issues and policies related to it. From the end of the last century onwards and more recently, with the sense that issues of urban pollution, water scarcity, heat islands, and flooding, partly due to climate change, impact well-being and have undesirable costs on lives and property, rainwater has been better understood, in particular from the perspective of being considered as a resource rather than being seen as a problem, following the logic of the urban water cycle (Goulden et al. 2018).

As a result, the urban infrastructure responsible for stormwater management has received more attention in terms of the necessary resources to keep it running, but so far it has not received sufficient funds and financing to cope with the increasing demands that are being made on it.

There is no single solution for the funding issue, and in each place, the funding policy reflects the particular context, but as the necessary amounts are quite significant, it has been necessary to count on government funds at all levels (federal, regional, and local) through general or specific budgets, plus contributions from users and the private sector, or even donations.

As an example, in the USA, a country of large dimension, and due to the variety of configurations and legislation, there are several ways of financing and organizing the provision of services, among which the well-known stormwater entities, existing 1,600, of the 7,550 allowed, with dedicated sources of funds such as fees and rates (EFAB & USEPA 2020).

In that country, where the annual operation, maintenance, and capital estimated funding gap for drainage systems is approximately USD7–10 billion (EFAB & USEPA 2020), as in many others, there are policy barriers to obtaining funds and financing that range from the popular perception of the importance of the systems to the existence of legislation that in some places requires popular consultations with minimum quorums of participants.

The EPA identified stormwater runoff as the single fastest-growing source of pollution in the country and, starting in the 1990s, began to regulate the issue through a policy that relied on the permit program through the Federal Water Pollution Control Act, better known as the already mention CWA. In this context, in the USA, since then, 7,855 discharge permits have been issued, according to the National Pollutant Discharge Elimination System (NPDES), which means a reach of 80% of the population.

The existence of systems with different characteristics, sometimes separate and other times combined, despite making matters more complex both in terms of those responsible for operation and maintenance and those who must provide the financial resources, does not prevent estimates of the financial needs. In research conducted in 2012 and published in 2016, the EPA estimated a need for USD67.2 billion over the next 20 years in investments both separate and combined systems. These amounts are equivalent to those spent in the past to initiate the construction of the interstate highway system or to upgrade wastewater treatment plants (EFAB & USEPA 2020).

In Brazil, between 2014 and 2033, the financing capital required according to the National Plan of Basic Sanitation – PLANSAB, in its version of 2013, is estimated at USD33.6 billion over the 20-year period or USD1.7 billion/year (Montenegro 2017).

The need for funds and financing mechanisms for this infrastructure is always raising due to regulatory requirements, water quality degradation, flood risks, climate change, and aging infrastructure itself, and the costs of doing nothing outweigh these costs. Thus, all alternatives deserve to be considered: general public budgets, fees, tariffs, grants, loans, revenue bonds, partnerships, PPPs, volunteer programs, and other innovative approaches (e.g., sponsorship of stormwater infrastructure).

Part of the necessary resources for stormwater management systems can be obtained from each owner of the impermeable areas, according to the type of use (commercial, residential and industrial) in proportion to what they contribute to the runoff plus what would occur if there was no impermeability, according to the user pays principle. The computation of these impermeable areas, however, is still not a simple task for a large part of the municipalities, which do not even have the staff and expertise for this, which requires measurements with the use of information technology and satellite images. The forms of cost attribution encounter technical and legal difficulties, and even in the USA, there is a lot of questioning, mostly demanded by non-residential owners, regarding both the legality of ownership for the imposition of fees and rates and the calculation of the parcels themselves. One aspect of interest is the proportion between areas of public responsibility, such as roads, squares, public buildings, and private areas. About this, in some locations in the USA, measurements identified between 65% and 75% of private areas able to receive green infrastructures (Dhakal

& Chevalier 2016) and in Brazil, specifically in the Federal District, the split was approximately 50% between public and private.

Incentives through exemptions can also act as an incentive for private landowners to construct rainwater storage or utilization devices on their plots (e.g., green roofs) or to disconnect from public stormwater systems, leading to savings. Another form of incentive is paid to municipalities for the discharge of treated water of specified quality levels into receiving waters, as is already the case in Brazil, but only for wastewater effluent, which could be extended to stormwater. Brazil adopts a similar mechanism for effluents discharged into rivers, by ANA-PRODES program, that seeks to encourage greater treatment of effluents.

All these issues show that stormwater solutions are typical of complex systems that require the participation of all actors, involving multiple disciplines, and have a great capacity to measure various items so that they can be fairly and equitably distributed.

The issue is not only the quantification of runoffs, which can be considered through the calculation of impermeable areas but also the quality aspects that, although they can be indirectly estimated through the classification of predominant uses, also bring complexity in the evaluation, for instance, of the types of existing pollutants, requiring, in each specific case, control and treatment alternatives with different costs, which leads to the valuation of the charge according to the polluter pays principle.

Financing policies involve items related to environmental, social, economic, organizational, institutional, and political issues, which demand the kind of robustness only found with the participation of all actors and multidisciplinary foundation so that they obtain relevant results and leverage society's values.

## 4. DISCUSSION

To achieve positive results in terms of human and environmental demands, policies addressing urban stormwater management require the challenging confrontation of a broad and deep paradigm shift, i.e., a change in the status quo of the provision of these services.

The change, grounded in a view of stormwater as a resource rather than a problem, extends to the services that can be achieved through its use and not simply by controlling its quantity and quality, i.e., by taking care of floods and their contamination and pollution. The position as a component of the urban environment, attending the role of participating element of the urban water cycle and contributor in the achievement of the SDGs requires its accounting not only in economic terms but as a contributor of valuation aspects under other criteria, as of amenities: urban ecology, recreation and aesthetic attractions to the cities.

Concerning the role of rainwater as a resource, an idea present in the new paradigm of urban stormwater management, the epidemic of COVID-19 highlighted the need not only for policies to universalize water supply through traditional sources (surface water, groundwater and desalinated water) but also to implement policies to do so through the use of rainwater. For example, the political decisions to suspend supply cuts during the pandemic due to the default of low-income families, in several states in Brazil, as well as the free distribution of residential water tanks to this part of the population, in the state of São Paulo, demonstrate the need for policies designed to address events such as this or the combination of multiple events (floods and Covid-19; dengue and Covid-19; drought and Covid-19), for which policy can and should consider the use of rainwater.

Economic aspects can be significant from several perspectives such as the savings provided by stormwater when compared to treatment or use permits from other sources and even expensive flood control structures, or about the energy consumed by reuse water or desalination. The control of pollution at the source has been reported to be less costly than the traditional 'end of the pipe' control.

The management structures, however, as they exist today, centralized and with few staff and expertise, are not sufficient for the decentralized service required, which demands adaptation of operational and organizational structures, the same happening with institutional structures such as laws, decrees, and regulation that lack experience in the matter (Montenegro 2017).

Concerning social actors, their participation is more necessary than in the centralized model in which decisions are made under technological viewpoints only, without taking into account other perspectives in management.

The consideration of interested actors from the point of view of resources and the financing of services necessarily brings about the perspective of their economic sustainability and the ways to make it feasible (Azevêdo 2019), causing policies to be designed 'with the public' interested not only in the provision of services but in the planning of feasible actions and operations with economic sustainability over time.

Finally, the inclusion of little-used innovations in the policies, represented, for example, by real-time monitoring and remote operation technologies coupled with meteorological data and flood warning systems, also has the potential to include more efficiency and economy in the operation of the stormwater systems.

Where they exist, drainage policies are reflected in legislation and codes to a greater or lesser degree of detail and also in policies and practices for funding and financing. For the most part, the legal, institutional, organizational, and management structures are linked to urban flooding issues or pollution control issues. Despite all the available knowledge, whether sufficient or not, policy decisions on stormwater are at present very tentative, if not non-existent. The paradigm shifts from considering rainwater as a problem to an opportunity and a resource requires a policy change.

From this point of view, its use can result in a decrease in the needed amount of city water supply and even in the quantities of water to be treated and drained to the receiving water bodies.

The interrelationship between water supply and wastewater systems and urban stormwater is therefore clear, including concerning the revenue that each system generates, remembering that in many places wastewater revenue is linked to the drinking water supply and therefore a reduction in drinking water consumption through switching to rainwater has an impact on tax collection.

The obstacles related to the amount of funding as almost insurmountable barriers without advancing on the growth forecast of increased urban rainfall that already occurs and without quantifying them makes the unquantified resource an absent element of policies.

For stormwater to become part of policies, it is essential to quantify it under a new paradigm in which it is considered as part of the solution, rather than a problem, and thus perceived by the population, as policies result from perceptions of reality that arise from conflicts between actors. Such perceptions, felt by policy and decision-makers, are not always based on reality, but on what is perceived by them.

Thus, the academy has the task, initially, of quantifying stormwater, which should be done locally and, finally, contribute to the explicitness of the necessary paradigm shift in its various aspects, economic, social, and environmental, proposing technological and management solutions, and with the support of an actively participating society, so that the steps to be defined do not remain only on paper, as happened with the MDGs.

There is already a concern about meeting the SDGs on several fronts, especially in the academy, which is reflected in a few publications and studies on the relationship between urban stormwater management and SDGs. Some aspects were presented, which are, however, worthy of further reflection to increase knowledge and understanding of the relationship between stormwater and SDGs, pointing out the need for ways to measure its effects.

The road may seem long, but if the first step is not taken, which is quantification and planning that take into account storm-water, followed by the development of policies under the new paradigm, supporting them with institutions and structures, and the implementation under appropriate management and supervision, the provision of urban stormwater management services in a sustainable manner will be a very difficult and more complex task.

The existing examples and experiences gained over the years through Integrated Water Resources Management (IWRM) or Integrated River Basin Management (IRBM) policies that present lessons of success and failure and their difficulties in implementation (Tortajada & Biswas 2018) deserve to be well analyzed for policymaking under a new paradigm. There are also economic instruments based on the polluter pays principle, formulated by the OECD in 1972 and adopted by the Council of European Communities in 1975, such as systems of fines and bonuses where fines must be higher than the profits gained from pollution and bonuses must be greater than the cost of pollution abatement, but these are instruments that require accurate information on the amount of pollution.

Finally, when considering the necessary participation of actors, one should not lose sight of the fact that consensus solutions should prevail, knowing that consensus does not mean unanimity, much less is carried out by actors on equal terms and resources, even if policies can be understood as resulting from conflicts of interest between participants with diverse interests and objectives in democratic contexts of participation, and more, that what we have today is the result of the application of successive public policy choices made previously, that is, it depends on the paths built by previous policies shaped within the optics of an old and aged paradigm.

As examples of successful Water Sensitive Urban Design (WSUD) policy implementation in Australia and the USA, from which relevant numbers and conclusions can be drawn, can be cited: Etowah HCP Stormwater Management Policy in Georgia, USA; Portland's Downspout Disconnection Program, in Oregon, USA; Nine Mile Run Rain Barrel Initiative in Pennsylvania, USA; KC'S 10,000 Rain Gardens Initiative in Missouri, USA; Victorian Stormwater Initiative (and Clause 56, etc.) in Melbourne, Australia and Healthy Waterways Partnership in SE Queensland, Australia (Roy et al. 2008).

In terms of figures, one important aspect, perhaps the greatest, concerns the number of impervious surfaces, as these areas generate surface runoff that should be the target of public policies for the management of rainwater runoff that encourage its reduction over time, for example, by using the polluter pays principle. Some examples are worth noting: (1) in the German city of Munich, since 1995 more than 4.5 million m2 of impermeable surfaces have been removed, resulting in a reduction of runoff by 3,000 million L per year; (2) in Melbourne, Australia 608GL (more than 300,000 L per household) are generated on the streets and roofs in an average year with 650 mm rainfall. Policies designed with appropriate incentives, based on the polluter pays principle, can generate benefits for all, with reductions in Water and Sanitation Services bills, for German cities, estimated to average 14% with the potential possibility of reaching 28% with optimization of stormwater use (Vietz et al. 2018).

## 5. CONCLUSIONS

This research discusses the policies regarding urban stormwater drainage and management services, where they exist, from a theoretical perspective, i.e., their relationship with existing institutional and regulatory frameworks, but also from a practical perspective, by addressing ongoing actions that seek to implement these policies in various locations and those global policies, such as SDG6, that should be present across the board in all countries.

The contribution of this paper brings elements to reflect on what exists but also on what remains to be done to ensure that stormwater management services take their rightful place among the various urban services offered to the city's population. The existing gap, however, presents itself as demanding a paradigm shift that is necessary to make the provision of these services not just a wish but a reality.

Besides the conclusion that a paradigm shift is necessary and involves technological (e.g. source control), social (e.g. multi-stakeholder participation), economic (e.g., equitable and multi-source funding), managerial (e.g., hybrid centralized and decentralized), institutional, regulatory, and organizational (e.g., legislation and structures) and many others, there is a strong emerging view that policies for stormwater infrastructure and services must be premised on meeting multiple challenges simultaneously such as epidemics (e.g., dengue, Covid-19) and other events that occur at the same time as flooding or scarcity. Therefore, they must be flexible and embrace the concept of dynamic resilience of complex urban systems and the infrastructure that supports them.

By considering these concepts, political solutions might be more successful since they will have the capacity to adapt according to the evolution of events that demand them, abandoning the static and rigid vision of policies centered on conservatism and the maintenance of the status quo, whatever it may be.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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First received 22 February 2022; accepted in revised form 3 April 2022. Available online 13 April 2022

# C Appendix to Chapter 5 – Article published in Water Policy - 2022

Regulation of urban stormwater management is not a matter of choice, but performance

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ABSTRACT

Public services regulation is not a new subject and neither is its application to urban water services. Regulation is part of the set of instruments available for running public policies but does not occur alone, i.e., without institutions, the rules governing inter-actions between actors. However, when it comes to stormwater management, regulation is not always present, either in a soft form, through best practice guides, or in harder forms, such as command-and-control mechanisms. Literature and practice show that their absence hinders the desired provision of stormwater services. This paper seeks to present and discuss aspects related to the subject of regulation focusing not only on the need for regulation but also on the alignment between policies, institutions, and regulation (PIR) around the goal of achieving performance in delivery services. The objective and novelty of the reflections presented here consist in contributing to create a new mentality on the need for this alignment. Aligning regulation issues within the PIR context creates opportunities to save resources and to bring better performance. This is not few and nor a matter of choice, but of the need to improve performance to face urban demographic increase, aging and obsolescence of infrastructures, and climate change challenges.

Key words: Mentality change, Public policy, Regulation, Stormwater management, Utility services

HIGHLIGHTS

This text goes beyond the precipitation of rainwater; it is about brainstorming. Brainstorming of aspects situated in this lackluster interface between the regulation and management of urban stormwater services. It seeks not only to illuminate the penumbra that exists there, but also to provoke more than just reflection. It seeks to encourage action from those who decide which public policy changes are necessary

## INTRODUCTION

Policies, institutions, and regulation (PIR) are part of a set of interconnected aspects that determine the incentives for the adequate provision of services. Policies provide the guidelines for action, and institutions (formal, such as laws, and informal, such as habits and behaviors) are the rules of the game, i.e., they govern the set of inter-relations between the actors (government, private initiative, and civil society) that participate in the actions (North, 1990), institutions limiting and defining the actor's decision space (Geyler et al., 2019). Regulation controls the progress of actions and results toward the goals set by policies. The alignment of these three aspects around the goal of adequate service delivery allows the desired results, and when this does not happen, performance is insufficient to meet society's expectations (Mumssen et al., 2018a).

In cities where wastewater and stormwater runoff systems are combined, the management and regulation of sewage systems are carried out jointly, with no explicit mention of stormwater runoff systems. In the case of separative sewer systems, the need for the regulation of these systems becomes more evident as they are clearly shown to be a public service, independent of wastewater, and as such should receive economic and financial support in addition to having the quality of their service performance evaluated.

The fact that the management of these services is carried out directly by municipalities and that their costs are borne by general municipal budgets contributes to the prevalence of the view that their effects on the well-being of society are not as relevant as they are. Another feature that reinforces this view is the fact that their use is little noticed, i.e., only during rainy periods when stormwater drainage systems and infrastructure are effectively in demand.

The reality, however, has been altered in recent decades as a result of: demographic changes, which have produced increased storm runoff due to the growth of sealed urban areas; climate changes, which are producing both increased rainfall (frequency), higher peaks (intensities), and durations (volumes), and shortage events while runoff infrastructure is aging and becoming obsolete. These facts make budgets insufficient for all demands, whether in quantity or quality.

Thus, stormwater management becomes significant within the urban water cycle, whether during times of scar-city or abundance, in the first case considering the possibility of its use as a resource and in the second due to the need of controlling it, avoiding damage and pollution.

The regulation of these waters is, therefore, a question of economic and environmental efficiency, not only in the use of an available resource but also in the management of the other material and environmental urban resources present. Stormwater regulation is not just an option but an effective way to increase the performance of urban systems and the well-being of cities.

Regulation can be defined as the control, exercised through self-regulation, contracts, or by a public agency over the activities that have value for society and involve establishing and ensuring the application of rules, whether economic as, for example, the setting of tariffs or of service delivery and quality standards, and may include goals of access and equity (Marques, 2005).

Thus, the establishment of, for example, a policy of charging tariffs on the waterproofed areas on each lot, sup-ported by clear and fair rules (institutions), allows the regulation to determine acceptable levels of tariffs to encourage demand management by users and contribute to efficiency gains by suppliers. Such a policy, supported by established rules (the institutions) and enforced through appropriate regulation, aligns the PIR tripod and creates incentives for runoff reduction acting as a driver to the improved performance of urban stormwater runoff systems. So does a policy of subsidizing the construction of stormwater ponds on lots.

Similarly, the establishment of stormwater policies, such as Water Sensitive Urban Design (WSUD) in Australia, requires that in addition to formal institutions (e.g., laws and ordinances), informal ones (e.g., customs and behavior's) and enforceable regulation are all aligned and properly accepted by the society to produce effective results.

Regulatory changes or reforms will be introduced by diverse actors such as politicians, policymakers, senior government officials, and donors will choose what types of policy, institutional, and regulatory interventions and what incentives will be encouraged with them.

The will of political actors alone cannot, however, promote the necessary long-term incentives, especially given the alternation between administrations (Kresch & Schneider, 2020), but when regulatory incentives are aligned with local needs and institutional capacities, good results in terms of service delivery can be achieved (Mumssen et al., 2018b). The water sector may suffer from political interference such as, for example, the practice of reduced tariffs for electoral purposes, reflecting on the performance of service provision (Berg, 2013).

This paper aims to analyse some issues, not very frequently in the literature, related to the urban stormwater management service regulation. Its relevance is debated using international experience, understanding that this discussion may contribute to reflections, mind change, and to decision-makers in achieving better performance results.

This article, based on a methodology of narrative analysis and case studies, refers to what exists in the literature and practice, and seeks to reach the subject of regulation from the point of view of its connection to political and institutional aspects and how the alignment between the PIR makes the enabling environment for the effective-ness of actions. It makes several contributions to the literature since curiously there are few publications discussing these matters. Besides the discussion and the relevance of the topic, the paper reviews and analyses several international experiences of stormwater management regulation.

It is necessary to point out that there are limitations in the methodological approach adopted, especially due to the literature span and countries discussed, which, although far-reaching, evidently did not cover everything that exists, and the same can be said about the authors' experience.

The paper is organized as follows. Section 2 deals with the technical and economic regulation of stormwater systems. Section 3 presents the international experience in the regulation of stormwater systems. Section 4 analyses the Brazilian case, a developing country, because it is a case with recent regulatory initiatives, still under construction, which can be an example for other developing countries and also on how the PIR alignment can work. Brazil was also chosen due to the proximity and knowledge of the authors on the regulation in this country. Section 5 discusses the results and section 6 draws the main conclusions.

## 2. REGULATION OF STORMWATER SYSTEMS

### 2.1. Quality and equity as objectives – technical regulation

For a long time, attention on stormwater runoff was focused on solving quantitative issues, i.e., water volume. As a result of this view, the quality of stormwater runoff, plus the pollution it carries, only became important after studies demonstrated that runoff is a significant source of contamination of the environment and receiving water bodies (Todeschini et al., 2014).

Both urban runoff that occurs during wet periods and dry periods, such as runoff from agricultural activities (e.g., runoff from landscape irrigation), began to receive attention as sources of pollution produced by human activities.

The regulation of service quality emerged in many places based on the pollution perception. Linked to storm-water pollution, as it was in the USA in the 1980 s, through Section 402 (p) of the Clean Water Act (CWA) enacted in 1972, based on the Federal Water Pollution Control Act, enacted in 1948, CWA establishes the basic structure for regulating discharges of pollutants into waters of the USA.

Quality regulation is generally carried out, taking into account criteria and parameters not only present in laws and regulations but also with the use of performance indicators, which are widely used since the 1990 s (Bolognesi & Pflieger, 2021), and should evolve in the stormwater sector, considering not only pollution aspects, but also others related to the provision of urban services not so easily measurable. These services include those associated with the well-being of cities, such as heat islands, water recreation, and urban beautification, which are classified as amenities (Coutts et al., 2013), as well as the growing use of stormwater to replace traditional potable water uses, such as toilet flushing and the irrigation of green areas.

Technical regulation is now focused on managing the quality of the stormwater resource rather than the quality of the assets that transport or accommodate the physical volumes of stormwater, and this is a result of the paradigm shift that is underway involving a shift in focus from quantity to quality management. The demographic growth of cities, combined with the aging of existing infrastructure and climate change, means that quality aspects are added to new quantity aspects, creating new performance and regulatory standards for urban stormwater systems.

More than that, in places where the universalization of services has not yet been achieved and in which economic and social inequality is a striking feature, as is the case in Brazil, regulation should seek not only purely economic objectives and goals, but also others that imply the inclusion of the excluded and equity in access and use of urban water systems.

Universalization as a policy goal and regulation as an instrument to achieve it, as intended by the new Brazilian water legal framework, should also be built taking into account solutions for urban water in slums and the peripheral urban fringes, located at the urban–rural interface.

2.2. Regulation as an incentive for efficiency – economic regulation

Economic regulation of municipal stormwater services, either public or private, is affected by the new technical and quality regulation requirements and standards as they affect costs and are transferred to tariffs within limits set by economic regulators. This is the case in England and Wales (Molinos-Senante et al., 2020).

Economic regulation also achieves aspects of equity in the use of infrastructure by promoting through the user and polluter-pays principles, more equitable distribution of burdens on those who are responsible for larger sealed areas (e.g., large parking lots), and higher pollutant loads (e.g., industrial and commercial areas) in the runoff than was previously the case, with system costs falling on everyone.

Economic efficiency and competition, although not an end in themselves, are instruments used to achieve economic and social developments as ultimate goals. In the absence of competition, efficiency losses occur, as is the case of monopolistic markets such as water services, characterizing the so-called market failure, thus giving rise to the participation of the regulatory state to act to compensate for this failure, and circumvent, through regulation, the power of monopolies and the lack of competition (Marques, 2010).

There are also other market failures, the so-called externalities, through which an individual suffers positive or negative effects of the activities of others. Network externalities, in which the existence of a network benefits the users who participate in it, occur also in stormwater management systems, raising the issue of non-exclusion of access and non-rivalry in consumption, which allows the emergence of the phenomenon of ‘free rider’, in which users participate in consumption but not in the provision of services, leading to inefficiency.

Regulation can, therefore, be seen as a source of incentives for efficiency in service provision. One way to create these incentives is through a tariff policy that includes productivity earnings, which can lead to the formation of municipal consortia, especially when the municipalities realize that the economy of scale offsets the higher trans-action costs of shared management (Narzetti & Marques, 2021).

The determination of fair and reasonable tariffs, which consider the measurement of impervious areas over which precipitation occurs, is divided into two parts, i.e., the public, consisting of roads and public places such as squares and parks as well as public buildings, and the private, consisting of properties and buildings under a private domain (Ribeiro, 2016), constitutes an economic incentive for the good use of soil and storm-water. By reducing soil sealing, it will be possible to obtain more efficiency in the use of infrastructure favoring its economic support from the perspective of the user-pays principle. The use of rainwater as a resource, for example, for non-potable uses (toilet flushing and garden watering) is configured as another form of efficiency, not only through savings in the use of water supply, but also a decrease in revenue related to water supply and wastewater tariffs, without a reduction in the use of sewerage infrastructure which can be configured as an economic inefficiency. Besides that, the pricing structure where wastewater costs are estimated from water supply volumes does not encourage the use of rainwater as it leads to the loss of revenue by reducing the water supply metering. The simplicity of revenue determination and tariff regulation from this type of pricing structure becomes a disincentive for efficiency when rainwater use comes into the picture. In this way, the price and tariff structure are barriers not only to the use of rainwater as a resource, but also to the full use of the urban water cycle, and consequently can delay universalization where it has not been achieved (Machete & Marques, 2021), which is one of the objectives of regulation.

Another type of inefficiency arises from the exclusion of part of the population, implying a loss of economic scale and revenue. The tariff affordability should be considered so as not to exclude from the services those com-munities with lower incomes. As suggested by Gomes et al. (2008), in a calculation methodology aimed at financing urban stormwater systems, the water supply, wastewater collection, stormwater services, urban property, and land taxes should be limited to a total of 5% of the household's income.

In the case of combined system (CS, wastewater and stormwater), the estimated portion of operation and maintenance costs incurred by stormwater is between 20 and 35% of the total, and the amount of capital investments is around 30–50% of the total of these systems (Abdelmaki, 1999). These values, if confirmed, according to the characteristics of each location and service provider, deserve to be segregated and accounted to the stormwater systems in terms of revenues to contribute to their economic support.

Furthermore, in combined wastewater systems, charging is done usually through a percentage on the water bill and this includes an estimated charge for wastewater services. In the absence of stormwater regulation, there is undue taxation of a service that is not provided, i.e., of stormwater regulation, which is yet another type of economic inefficiency.

At last, concerning regulation costs, the creation of stormwater regulation brings costs to providers that are reflected in the tariffs, through regulation fees, which can be significant for smaller municipalities with less than 10 thousand households, due to economies of scale. As pointed out, multisector regulation (joint regulation of several sectors such as electricity, gas, and water) could be an alternative to reduce regulation costs (Henten et al., 2003; Jordana & Levi-Faur, 2010). Another alternative is the union of municipalities in regulatory consortia, which allow the dilution of costs among several municipalities, as is being proposed in Brazil.

## 3. INTERNATIONAL REGULATION OF STORMWATER SYSTEMS

### 3.1. United States (USA)

The first country to be included in the study is the USA because it is where the federal regulation of urban storm-water is at a very advanced stage and where it has even pioneered the adoption of stormwater utilities as a way to organize the collection of funds to meet the increasing demands (since 1948, with the Federal Water Pollution Control Act –FWPCA) for strict legislation for the control of diffuse urban stormwater pollution in municipalities of all sizes.

In the USA, where stormwater utilities are widely used in the operation, management, and disposal of urban stormwater, regulation is originated from concerns over effluent quality and the contamination of receiving bodies and is mainly carried out through determinations issued by the Environment Protection Agency (EPA), since 1972, in accordance with the CWA. According to the EPA, the regulated area comprises 4% of the American territory but corresponds to more than 80% of the total population.

The concern with the quality and pollution of receiving water bodies was the motivation for the control of surface runoff that occurs mainly through the Municipal Separate Storm Sewer System (MS4), i.e., the transport systems of stormwater runoff, neither to be confused with CS, nor with the systems of the treatment of runoff effluents.

Discharge authorizations are a requirement for MS4 operators, as are stormwater management programs to prevent the input and conveyance of pollutants through the MS4. The programs detail the measures taken to control pollutants and state authorities are assigned responsibility for the National Pollutant Discharge Elimination System (NPDES), and in some locations, this is carried out by the EPA as the responsible authority (Office of Water, 2005; EPA, 2010).

Since 1990, NPDES-compliant discharge permits have been required of MS4 operators in two phases: phase I, in 1990 (regions with more than 100,000 inhabitants; construction activity disturbing 5 acres of land or more; 10 categories of industrial activity; 855 utilities; covered by 250 Individual Permits) and phase II, in 1999 (regions with less than 100,000 inhabitants; small construction activity disturbing 1–5 acres of land; 6,695 utilities; covered by State General Permits (SGP), but some states use individual permits). There are also three watershed permits covering 3 phase I and 40 phase II MS4 (Collins et al., 2012).

The development of phase II involved extensive stakeholder participation through consultations convened in a committee, constituted under the Federal Advisory Committee Act (FACA), with representatives of small entities and comments about the proposed rules submitted by more than 500 individuals and organizations during 90 days of public consultation.

In 2020, a survey collected information about the stormwater utilities. The regulatory requirements they were subject to, presented, as a result: 100% of the sample utilities are submitted to an MS4 permit; 51% to total maxi-mum daily load (TMDL); 49% to NPDES wastewater discharge permit; 10% to combined sewerage/excess/long-term control program (LTCP); 7% to other special permits; 7% to sanitary sewer overflow (SSO) management plan; and 4% to integrated watershed permit (Black & Veatch, 2021).

The survey, in terms of decision priorities and levels of annual capital expenditure, pointed a score of 3.9 to regulatory compliance, on a scale of 1–5 (very strong), ranking third, after the management of stormwater conveyance infrastructure (2nd) and flood control (3rd). For the item that contributes most to improving management, the expansion of regulations came fourth, with a score of 3.7, after funding adequacy (1st), aware-ness and support of society (2nd), and aging infrastructure (3rd).

There is state legislation authorizing the collection of stormwater tariffs by municipalities (84%), and the col-lection of tariffs is carried out on an area basis (according to 89%) with total areas or impervious areas computed (86%) and in the remaining 14% both types.

The computation of areas is based on aerial and digitized images of the impervious areas (54% of the answers) through the analysis of the footprints of the buildings from the tax systems (28%), a total gross area with an impervious factor (9%), and other methods (9%). The type of residential charging structure is based on: uniform tariffs (flat fee) (66% of respondents), calculated individually on a case-by-case basis (12%), and 22% stating that they use tiered tariffs in up to five levels. The average monthly residential tariff value, different in each state and city, varies from US$ 0.84 to US$ 25 (Black & Veatch, 2021) and is related to aspects of geographic location, population density, and home value (Kea et al., 2016).

Register updating of total and impervious areas of units is carried out through the Geographical Information System (GIS) (Sydnor & Dunn, 2015) in 59% of respondents.

Prices are considered by users as affordable or most affordable in 68% of respondents. Most of the utilities (68%) inform that they do not offer discounts. There are exemptions, based either on legislation or on the utilities’ own rules, for certain areas such as streets, roads, public spaces, or public passage (63% of the utilities) and several others.

Most utilities (79%) did not face legal challenges (McGovern & Hampton, 2016) and the remaining (21%), mostly were challenged by users in the non-residential categories (79%), regarding the collection of tariffs.

There is a provision of incentives for reductions in runoff volumes and peaks, water quality, education, direct discharge into surface water bodies, good practices (such as oil separation and sweeping), and zero discharges. The modalities of incentives are cost-sharing (60% of respondents), design assistance for best management practices (BMPs) (50%), discounts for implementation (20%), reduced interest for loans (10%), and stormwater grants (30% of respondents).

In the USA, CS are designed to collect and convey large volumes of stormwater and wastewater, while the sewerage system (SS) conveys only small amounts of stormwater and groundwater to treatment plants. These result in overflows that cause the contamination of water bodies and return to buildings with adverse health effects. These occurrences are due to blockages, bursts, defects in pipes and networks, pumping failures, or design and vandal-ism and are, according to the EPA, responsible for about 23,000–75,000 SSO events annually, disregarding the returns to buildings (EPA, 2022).

Concern about these events has led stormwater management programs to take them into account by setting as one of their objectives the reduction of pollutant discharges to certain levels considered to be the ‘maximum practicable’ or the maximum extent practicable (MEP), protecting water quality and complying with the CWA.

Phase II MS4 programs consider stormwater as point sources of discharge and rely on six joint minimum objectives to achieve the MEP: education and outreach on stormwater impacts (Biehl & Buechter, 2011), societal engagement, elimination of illicit discharges (Irvine et al., 2011; Derrick & Moore, 2015), construction of runoff controls, post-construction stormwater management, management in new and rehabilitated developments, and the implementation of best practices and pollution prevention for municipal operations.

3.2. Europe

In Europe, stormwater management falls under the Water Framework Directive (WFD) 2000/60/EC – eco-centric – and also the Floods Directive (FD) 2007/60/EC – human-centric (Jensen et al., 2020) – the latter integrated with the former to promote integrated management by the catchment, but with specific variations in each country, produced by a mix of regional and central agencies, but not always adopted in local legislation. The focus, however, refers to aspects of water quality and quantity, mainly directed at the receiving water bodies, leaving the approach on the origin and generation of urban runoff to a secondary level, without even mentioning the term 'stormwater' or, in a more detailed way, the economic aspects of regulation, such as the polluter-pays principle for stormwater management systems with the sharing of responsibilities for the generation of runoff in qualitative and quantitative terms.

The WFD refers to drainage only twice (Jensen et al., 2020), firstly when dealing with the artificialization or modification of surface water bodies that suffer from the effects of rainfall-runoff draining onto land, and secondly when identifying potential groundwater pollution through recharge with runoff from rainfall drained artificially into groundwater.

In Germany, there is increasing decentralization in urban stormwater management, and regulation is carried out by municipalities using mainly incentive instruments such as tariffs and discounts on usage and compulsory connection, following the establishment of local and national laws and codes and multidimensional objectives. Decentralization receives, however, questioning due to the loss of economies of scale and the high transaction costs involved (Bedtke et al., 2019). The disconnection of impervious areas contributes to the better performance of the systems and is an important aspect to be regulated. In areas of dense, consolidated urbanization, however, it encounters many obstacles. The city of Berlin, which has a separate system, was analyzed with the use of GIS technology, and the result concluded that it is possible to easily disconnect 30% of the impervious areas (Sieker & Klein, 1998).

In France, the existence of some 36,000 municipalities makes it difficult to comply with the principle of subsidiarity, especially regarding urban stormwater where ownership and problems are under the responsibility of the communes and therefore the control and regulation of services lie at the local level. Nevertheless, water agencies are responsible for setting charges to users for water use, leading to the financing of wastewater and stormwater infrastructure with resources obtained from water bills, which raises questions as the French option is for a separate wastewater system and there is also a provision in the law for associations of municipalities to charge for stormwater management (Barraqué, 2013).

In the United Kingdom (UK), since the water system privatization, the body responsible for the economic regulation of water services is the Office of Water Services (OFWAT), while quality regulation is a responsibility of two agencies: Environment Agency (EA) and Drinking Water Inspectorate (DWI). The governance of this system has become more complex and sophisticated, but paradoxically with budgets that do not grow in the same magnitude as the demands, which is a great challenge. There is a Sustainable Drainage Systems (SuDs) guidance, produced by Construction Industry Research and Information Association (CIRIA), with aspects of compliance to the SuDS principles that is followed by all actors and serves as regulation rules.

### 3.3. Australia

Australia, which has undergone a long transition process concerning urban water over the last decades, highlights the fact that policies are not implemented on their own and depend on instruments such as regulation to make them work. Like policy frameworks, regulation is part of a set of factors conditioning actors' behavior and can be classified in two formats: 'soft' like policy frameworks or best practice guidelines, which only encourage behavior, or 'hard' like command-and-control structured regulation, which compels it. The Australian policy shift toward WSUD was characterized by several phases and the coexistence of 'soft' and 'hard' regulations. Initially, there was a successful phase with an institutional reversal creating the perception that transition processes of complex systems require regulation and attention in their trajectories as was the case of the transition from the traditional model of urban stormwater management in South-East Queensland to WSUD (Werbeloff & Brown, 2016). Anyway, in the most important urban areas such as the Sydney metropolitan area in New South Wales or the Melbourne region in Victoria, the multisector regulators set tariffs and quality guidelines for the stormwater systems (by Independent Pricing and Regulatory Tribunal – IPART in the former and Essential Services Commission in later).

### 3.4. Other regions

In Latin America, regulation is almost non-existent and even in Chile, considered as an example of water regulation, there is no specific regulation for stormwater.

In China, there are projects implemented locally, at the municipal or sub-provincial level, under the Sponge Cities Initiative (SCI) program, a national initiative for the construction of sponge cities. Under the Low Impact Development (LID) idea, the central government program has edited a preliminary technical guideline, aiming to establish a regulatory structure, but still lacks financing and management models such as Public–Private Partnership (PPP) arrangements, which, despite being encouraged (Jiang et al., 2017), do not yet have mature legislation and regulation (Zhang et al., 2019). In the prosperous city of Ningbo, for example, which is undergoing rapid expansion, only one PPP project was initiated until 2018 according to government information (Griffiths et al., 2020; Qi et al., 2020).

## REGULATING STORMWATER SYSTEMS IN BRAZIL

### 4.1. Introduction

In Brazil, according to legislation (decree no. 7.217/2010), urban stormwater management services include urban drainage, urban water conveyance, detention and retention of urban stormwater to dampen flood flows, and treatment and final disposal of urban stormwater.

The public service of urban stormwater management, being a water service of local nature, i.e., a public function of common use to be provided locally, is owned by the municipalities and, therefore, its provision is performed directly by the municipality or by third parties under delegation (law no. 11.445/2007).

However, even though it requires a specific administrative structure and its own revenues for its proper functioning, most municipalities provide services directly without disentangling this service from other municipal functions, and accounting for their costs and other resources jointly. Besides, they usually do not count on dedicated revenues, legal instruments, and exclusive staff (Baptista & Nascimento, 2002).

Infrastructure related to urban stormwater management services is incorporated into the municipal assets and depends on the overall municipal budget for maintenance and expansion, or on state and federal resources which, in turn, have priorities that are not always identical to those of the municipality. The road system is part of the municipal urban stormwater systems and, as the latter is often considered part of the former, is included in the roads budget (Nascimento et al., 1999).

The integration and complexity of urban stormwater management involve aspects related to the road system, land use and occupation, management of permanent preservation areas, protection of aquifer recharge areas (Caprario et al., 2019), and flood mitigation, as well as care in endemic areas related to various diseases (malaria and dengue). The planning activity involves a coexistence between three plans: municipal master, Water Supply and Sanitation (WSS), and urban drainage, which are all mandatory for municipalities to obtain resources from other federal entities (Decree 7.217/2010). In addition to the dialogue between all these municipal plans, it is required to exist integration with plans for water resources, preservation areas, and hydrographic basins and health, which are activities that cannot be delegated (law no. 11.445/2007). Regulation and execution of services, which are also municipal responsibilities, can, however, be delegated to other entities, including consortia (Oliveira & Marrara, 2017).

4.2. The role of the National Agency for Water and Wastewater (ANA)

Recently, the regulatory landmark of water services was updated by Law No. 14.026 of 2020 intending to speed up the universalization of water services in Brazil. This new law was prepared in such a way as to allow for the standardization of existing experience and knowledge to make the universalization of services feasible and pro-vide for greater involvement of private capital, given the reality of fiscal stress and insufficient public resources to meet the necessary demands.

Among the new features, Law No. 14.026/2020 created a federal regulator (ANA) for water services with responsibility for establishing benchmark standards which are guidelines that subnational regulatory agencies must comply with. These guidelines should aim at economic sustainability, reducing costs, improving quality, and expanding the coverage of existing stormwater networks, all of which are aspects that depend on information about what exists, including how stormwater management is perceived by the population.

Reference standards will be prepared after listening, through public hearings, of all stakeholders and subnational agencies and, before coming into effect, submitted to a regulatory impact analysis (RIA). They will not be mandatory, but their acceptance will be a condition for access to federal public resources. It is also up to ANA the challenge of making water resource plans (basin level) compatible with the urban stormwater and solid waste (municipal level) plans (ANA, 2020).

This recent legal determination (Brasil, 2020), to assign responsibility to ANA for the elaboration of national reference standards regarding water regulatory issues in Brazil, has raised expectations of improving the performance and results of the sector. As to this, however, the observations made for water services, by Berg (2013), are pertinent, including urban stormwater management:

'…sector regulation must be embedded in an adequate and consistent institutional framework to have a positive impact on performance. Sector regulation alone is no guarantee of performance improvements in water supply and sanitation services. The case studies and empirical analysis suggest that without significant changes in the institutional environment, typical regulatory tools will not be effective. This finding is of concern, especially for developing countries, as it means that the creation of a regulatory agency may raise expectations, but ultimately the agency's rules may not be of improving the performance of the provider(s), without additional politically difficult initiatives being taken.'

4.3. Regionalization

To allow the universalization of services, an aspect of regulation, taking into account that a large part of the municipalities have deficits and receive subsidies from other municipalities through the cross-subsidization mechanism, the creation of 'blocks' of municipalities was encouraged by the new law to generate economies of scale turning blocks economically sustainable.

The design of 'blocks' considering only economic and tariffs aspects of WSS, without taking into account the costly infrastructure of urban stormwater, makes the intended integrated vision to suffer from the exclusion of a water urban cycle component that, in most countries, for a long time has no longer been considered as 'off accounting and economic regulation'. These costs are especially significant due to the effects of increasing rainfall related to climate change and its costly natural consequences like disasters. This non-inclusion, or just its consideration in a third level, can be deemed, however, a mistake in terms of management of the water urban cycle. From the aspect of cost recovery, if we want to seriously consider the performance and economic balance of the 'blocks', also the socio-economic-environmental quality existing today in the territories and that which is intended to be achieved with universalization must be taken into account.

Quantification is not an easy task, but one that must be faced under the unavoidable consequences in the construction of unsustainable 'blocks', whether economically or politically, calling into question the strategy of universalization by the use of regionalization or leading to enforced authoritarian decided solutions, under §3° article 52 of law no.

14.026/2020, which is in opposition to the principles of democratic participation present in the legislation (law no. 11.445/2007).

4.4. State regulation by agreement

In the municipality of São Paulo (SP), the largest urban agglomeration in South America, the regulation of water and gas is carried out through a multisector agency, the Water and Energy Regulatory Agency of the State of São Paulo – ARSESP (São Paulo, 2007). The investments in the municipality are defined jointly by the State of São Paulo and SP Municipality, according to the municipal and State Plans through a management committee com-posed of representatives of the two federative entities.

By means of law no. 14.934 of the municipality of São Paulo (Prefecture of São Paulo, 2009), an agreement was signed between the municipality, the State, ARSESP, and the São Paulo Water State Company (SABESP), aiming at regulating the shared offer of water supply and wastewater services in the municipality of São Paulo, provided by SABESP, valid for 30 years, extendable for an equal period, in which a minimum of 7.5% of gross revenue from services (after the deduction of certain taxes) is allocated to the Municipal Environmental Sanitation and Infra-structure Fund (FMSAI), and 13% is earmarked for investments in water and environmental actions. The FMSAI is accounted for and operated by the Municipal Housing Secretariat and managed by a council that must apply the resources according to the investment priorities contained in the Municipal Sanitation Plan, as shown in Figure 1.

The fund's actions (Figure 1) focus on aspects related directly or indirectly to stormwater urban water management, such as cleaning, depollution, and channelization of the water lines, the implementation of systems to capture, store, and use stormwater in public facilities and areas of influence or occupied predominantly by low-income populations, the implementation of linear parks and areas to protect natural conditions and of water production, land regularization, and social housing, and the improvement of mobility in areas of precarious settlements. There are positive aspects in the FMSAI institutional organization, especially regarding the maintenance of a permanent source of funding, although this is not exclusive to stormwater management actions, sharing resources with other areas, such as housing.

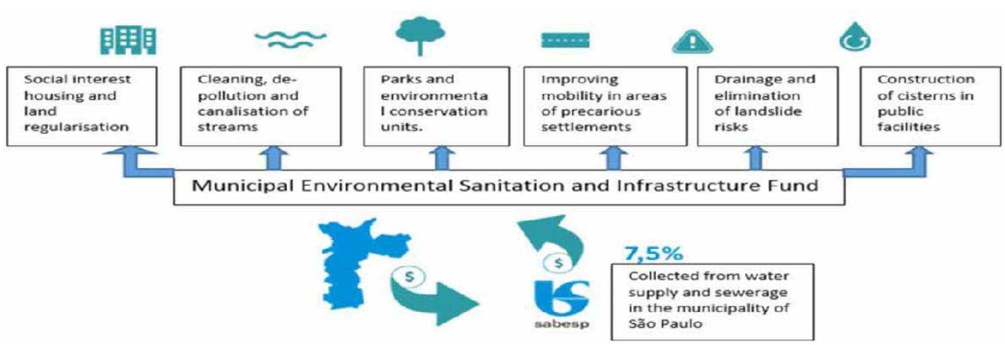


Figure - 1 Municipal Environment Sanitation and Infrastructure Fund (FMSAI) sources and applications (https://www.prefeitura.sp. gov.br/cidade/secretarias/habitacao/fmsai/apresentacao/index.php? p¼145635, adapted).

Within the scope of the FMSAI, however, the integration with other areas, such as health, environment, planning, water resources, land use, land occupation, and urban policy (some of which have seats on its Steering Committee), is seen as a positive factor, since water services are transversal and correlated with territory and society (Montenegro et al., 2021).

The linking of revenues from the stormwater management component to the water supply component, how-ever, deserves to be analyzed to verify if this form is not a limiting factor to the development of actions that are required for the efficiency of planning, management, and its regulation and inspection.

4.5. Stormwater regulation in the Federal District (Brasilia)

The lack of institutionalization of stormwater management services in Brazil is generally reflected in the absence of public entities specializing in the provision of these services, specific revenues to fund the activity, few urban stormwater master plans, integrated with municipal WSS plans, and no regulatory activities.

One of the few exceptions to this general picture can be found in the Federal District (Brasilia), where the Water and Power Regulatory Agency (ADASA) has been developing activities aimed at encouraging the structuring of urban stormwater management services, including aspects related to economic regulation, with support from the proposed tariff collection based on impervious areas and taking into account land uses and the population’s ability to pay, according to the legislation in force.

The barriers to the implementation of the proposals issued by ADASA, however, do not differ from the rest of the municipalities regarding the lack of specialization of the body in charge of the stormwater management, i.e., Urbanization Company of New Capital (in Portuguese, the Companhia Urbanizadora da Nova Capital – NOVACAP). This company does not have specialized staff and a concession contract and competes with other bodies for resources from the general budget of the Federal District (FD). Therefore, it finds obstacles to the maintenance of services in an adequate way, a fact that is reflected in the few investments for the maintenance and replacement of the dedicated stormwater infrastructure with the consequent and frequent flooding.

Concerning the planning, the existence of an Urban Drainage Master Plan (PDDU) and a Federal District Basic Water and Sanitation Plan (PSBDF) are important instruments, but in the absence of permanent sources of funds, they are of little use.

Ongoing efforts toward the quantification of impervious areas, whether public or private, will allow the individual estimation of each lot contribution to runoff to the existing public network and thus, also the calculation of the amounts necessary for the materialization of the user-pays principle and the economic sustain-ability of stormwater systems. The establishment of individualized tariffs with possible reductions to owners who have retention devices or other ways of using rainwater that falls on their lots, or even disconnection from the networks, may be possible and is a reason for regulation by the agency, as they constitute incentives to reduce runoff and associated costs.

The portion corresponding to the rainfall occurring in public areas, such as roads, streets, squares, and others for common population use and public buildings, should receive resources from the public budget. ADASA's study has computed that results for the percentage of impermeable areas in the Federal District of Brazil are 49% for private areas and the remaining 51% for public areas of the common use of the population (Montenegro, 2019).

Thus, the importance of regulation is visible in the actions and proposals made by ADASA, in which the regulatory agency develops relevant contribution by identifying and qualifying the alternatives for the institutionalization of services through the improvement of the organization of service provision and the study of the charging model to be adopted. This latter involves not only the costs of the system, but also the quantification of social tariffs, cross-subsidies, and other parameters necessary for the economic and quality of service regulation of the urban stormwater management in the Federal District.

Finally, the State's performance in its role as a planner, a regulator, and responsible for the activities at all levels of government and as a participant in the financing and management, following constitutional precepts, does not escape the focus of the debate on social democratic rights to water and also economic efficiency (Neto & Camkin, 2020).

## 5. RESULTS AND DISCUSSION

The absence of regulation as a performance leverage tool that should be part of stormwater management cannot be attributed to the lack of an object to be regulated but to the absence of its institutionalization and of policies. This arises from the fact that it is not present in the mindset and will of political decision-makers and the population, as one issue requires public policies and consequently with a gap in the provision of resources (Werbeloff Brown, 2016). As in other sectors, we may question the ideal moment to implement its regulation: before, during, or after the institutionalization of the activity.

This is, however, a false question, which may arise due to the erroneous view that only private concessions should be regulated. In its origin, as it is known today, regulation was originated in the USA and in the water sector in England and Wales, linked to privatization issues. However, in Chile, for example, the regulation of water services, which is considered successful, was initiated before their privatization (Ducci, 2007), but until now without no stormwater regulation. The regulation idea has evolved, and examples regarding the forms and moment of their implementation show that there is no general rule, but that, as well as the allocation of resources, it must always be present for better performance of the systems. In this scope, well-regulated private sector services, in addition to economic issues, may contribute to universalization. However, well-designed storm-water regulation also involves regulating the performance of the public sector which, as we have seen, is responsible for a large part of the impervious areas of the territories and consequently a large part of urban storm-water. Regulation is based on two pillars: economic efficiency and quality of service. Both require planning, contracts, and resources invested.

Stormwater management is an intermittent service and it is not always seen as important, so the investment always stays behind the required (Dobbs et al., 2013). It is only when disasters occur that political decision-makers are present, but with a short-term vision that often exacerbates the perception that only specific actions and funds earmarked for that specific event are the solution.

The institutionalization of economic and financial support for stormwater management systems requires a permanent flow of dedicated revenues, as is the case with stormwater utilities in the USA (Campbell & Bradshaw, 2021). It also implies the existence of regulation as a means of making resource flows more efficient economically and politically, according to defined policy goals, with equally explicit objectives of urban economic development (infrastructure growth and maintenance), environment (river clean-up), and social (well-being, people participation, and access to systems) seeking to bring equitable welfare to the entire population.

The economic regulation can meet multiple objectives as is the case of social tariffs in Brazil, Chile, Uruguay (Narzetti & Marques, 2020), Spain, and South Africa. Quality service regulation also show environment good results, like in Australia and the USA, or directly linked results to the performance of stormwater infrastructure networks, as occurs in Germany (e.g., in Munchen) with the incentives for the participation of the private sector in disconnection (Sieker & Klein, 1998).

In urban stormwater management systems, there is, all over the world, a multiplicity of situations and formats of management and regulation (Table 1) according to different stages of the paradigm shift underway in the sector. In Brazil, for example, the regulation of urban stormwater management systems is in its infancy, with few, diverse, and fragile rules drafted or in preparation, such as the future reference standards of ANA, awaiting experimentation and results. Brazil can still shift paradigm and put stormwater management as a priority. So, aligning regulation in PIR is key to increase organization and performance.

China is experimenting the institutionalization of the LID concept through the idea of sponge cities in 30 cities, but with results expected in the medium (2030) and long term (one generation). The country seeks to encourage PPP arrangements but does not yet have models for this (Jiang et al., 2018).

In other countries, such as the USA, the rules already have results from older applications, despite the great diversity of alternatives and Australia can be considered at an advanced stage, with broad voluntary participation of like-minded people including regulators, but with its own dynamics and diversity of regulation in each location (Radcliffe, 2018).

The general panorama of stormwater management, evidenced by the international and Brazilian examples, presented as a result in Table 1, shows that there is no influence of Gross Domestic Product (GDP) per capita, as it might seem, on the alignment between PIR. In the same way, one cannot affirm that the smaller or larger participation of the private sector, through the privatization of providers, as is the case in the UK, has an impact on PIR alignment, the same occurring with decentralization as in France and Germany, although in different formats. In Germany, a country where decentralization has a significant importance, good results are highlighted in some areas, such as Munich, which, however, deserve a deeper analysis of the institutional and regulatory structure. The two countries where the alignment is most noticeable (Australia and the USA), still partially, with some gaps in aspects and locations, leave questions to be answered, such as the how path dependency or institutional inertia contribute to existing alignments.

On the performance side, what can be said is that economic and quality regulation in the two countries where greater alignment is observed show positive results, both in terms of economic and environmental sustainability, without meaning that they cannot further improve.

## 6. CONCLUSIONS

The study has limitations because stormwater is a service of local responsibility, but subject to a multitude of PIR spread over all levels of administrative organization of the state, in all localities, which have distinct institutions, making it impossible for the literature to contain everything, and local research in many cities is extremely difficult, time-consuming, and costly. This is one of the reasons why the text contains many details from places where we have had greater knowledge, as is the case in Brazil.

The search showed that in one way or another, by contract or by agencies, or even in their absence (self-regulation), the owners, i.e., the municipalities, exercise control over urban stormwater management systems. Policies, institutions, and the institutionalization of the regulation and of resources allocation to urban stormwater management systems are a weak part of the organization and determination of performance, given the increasingly evolving demands and the lack in PIR alignment.

The greater or lesser degree of the alignment between policies, institutions (formal and informal), and regulation, as we tried to demonstrate with examples, according to each local reality, and the related performance of service provision, was not very well confirmed, but in both countries where some degree of alignment was found the perceived performance is high.

In the current situation, regulation, as well as the attention given to the institutionalization of urban stormwater services, is almost absent in many countries (Table 1). So, aligning regulation in PIR deserves to be better considered, firstly because regulation is a question of efficiency and resources saving, secondly because efficient management and use of existent infrastructures also has the potential to reduce the costs of climate changes improving capacity to economic grown and development. The lessons provided by the regulation of various sectors, together with the few initial experiences concerning urban stormwater, provide starting points for the evolution of the subject, which is expected to grow in the coming years. These are questions for near future research studies.

It should be noted, however, that the regulation of the stormwater sector is much more complex than that of other water and public services due to its hybrid public–private character with inseparable interaction between the two, as regulation should cover both public and private aspects of sealed territories and the water that falls on them, making it impossible, for example, for financing systems to be covered by only one part of this complex whole.

Finally, just waiting for the establishment of institutions that will take care of the regularization of land title or the implementation of the entire infrastructure to meet urban stormwater demands means abandoning the goal of water services for all, the Sustainable

Development Goal 6 (SDG6), perpetuating exclusion and inequality with obvious consequences for urban social cohesion and society inefficiency in many parts of the world.

In future studies, it may be interesting to choose places with recognized stormwater systems performance to verify what the PIR are and how they work, so that comparisons can be made, without leaving aside the fundamental question of the mechanisms instituted for the contribution of resources and their magnitudes.

Table 1 GDP per capita of some searched countries and PIR alignment.

| Country (US$ GDP/capita in 2020)[a] | Policy (P) | Institutions (I) | Regulations (R) | R Alignment |
|---|---|---|---|---|
| U.S. (63,206.5) | Pollution control, Low Impact Development – Best Management Practices (LID- BMP) | Environment Protection Agency (EPA) rules, Stormwater Utilities, Federal Acts, State and Municipal Laws | EPA Rules, MS4, NPDES, State and Municipal Laws | Aligned in many places, but not all aspects |
| GERMANY (42,252.7) | Pollution control and multiobjectives | Federal, Local (Länd) and Municipalities laws and Water Companies rules, Verbänd (river managers) guidance's, Water Framework Directives | Self-regulation | Not aligned |
| FRANCE (39,037.1) | Flood-control | Communes(Municipalities)laws, 6 Agences de L'Eau rules, Watershed institutions, contractual rules | Contractual arrangements | Not aligned |
| UK (41,059.2) | National funding of reduction flooding vulnerability, Sustainable Drainage Systems (SuDS) | Water Services Regulation Authority (OFWAT), Environment Agency (EA), Drinking Water Inspectorate (DWI) and Municipalities rules. Flood and Water Management Act, 2010 | No stormwater regulation, just Construction Industry Research and Information Association (CIRIA) – SuDS Guidance[b] | Not aligned |
| AUSTRALIA (51,680.3) | Water Sensitive Urban Design (WSUD) | Multisector Regulators, IPART (Independent Price Authority Regulatory Tribunal) and ESC (Essential Services Commission) rules | Each state has its own regulatory body and its own rules | Aligned in some places |
| CHILE (13,231.7) | Integrated Water Resources Management (IWRM) | Superintendencia de Servicios Sanitários (SISS) rules | No stormwater Regulation | N/a |
| CHINA (10,4343.8) | Sponge Cities Initiative – Low Impact Development (LID) | Technical Guidelines | No stormwater Regulation | N/a |
| BRASIL (6,796.8) | IWRM | Municipalities Laws, All levels Agency Independent Regulators rules | Few initiatives | Not aligned |

[a]Data.Worldbank.Org/Indicator/NY.GDP.PCAP.CD
[b]Kellagher et al. (2019)

## AUTHOR CONTRIBUTIONS

C.A.F.O.N. and R.C.M. conceptualized and visualized the whole article. C.A.F.O.N. conducted data curation and formal analysis. C.A.F.O.N. investigated the article, and C.A.F.O.N. and R.C.M. developed the methodology. R.C.M. administered the project, found resources, and supervised the article. C.A.F.O.N. and R.C.M. wrote the original draft and reviewed and edited the article. All authors have read and agreed to the published version of the manuscript.


## FUNDING

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.


## DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

## CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 5 May 2022; accepted in revised form 20 July 2022. Available online 3 August 2022

# D Appendix to Chapter 6 – Variables & Sources

| Variable | Description | Source | |
|---|---|---|---|
| aedes | Cases of Dengue, Zika, and Chikungunya - Brazil - Period:2019-2021 | Ministério da Saúde/SVS - Sistema de Informação de Agravos de Notificação - Sinan Net | Dengue + Zika + Chikungunya - Notificações registradas no Sistema de Informação de Agravos de Notificação - Brasil - Período:2019-2021 |
| ac_sw | Public urban roadways (km) without natural, or built, drainage systems. | Ministério do Desenvolvimento Regional / Secretaria Nacional de Saneamento / Sistema Nacional de Informações sobre Saneamento - SNIS | Diagnóstico de Drenagem e Manejo das Águas Pluviais Urbanas 2020 |
| pib_cap | GDP per capita, at municipal / local level. | IBGE, Produto Interno Bruto dos Municípios. Diretoria de Pesquisas, Coordenação de Contas Nacionais e Diretoria de Geociências, Coordenação de Geografia e Coordenação de Recursos Naturais e Estudos Ambientais | PIB dos Municípios - base de dados 2010-2019 |
| ac_ws | Total urban population at water risk, i.e., the population that due to poor or nonexistent water services is at water supply risk. | ANA / Ministério do Desenvolvimento Regional / Plano Nacional de Segurança Hídrica (PNSH) | Índice de Segurança Hídrica - ISH Humano com dados do Atlas Água |
| ac_ww | Total urban population without access to wastewater services. | Ministério do Desenvolvimento Regional / Secretaria Nacional de Saneamento [SNS] / SNIS | Sistema Nacional de Informações sobre Saneamento (SNIS - Série Histórica) |
| idhm | Human development index, at municipal / local level. | IBGE / PNAD 2017 / Censo 2010 | Atlas Brasil \| PNUD, IPEA, FJP |
| gini | Gini index, at municipal / local level. | IBGE / PNAD 2017 / Censo 2010 | Atlas Brasil \| PNUD, IPEA, FJP |

| | | | |
|---|---|---|---|
| | | Urban population density threshold | 2000 inhab/km2 |
| Climate | Urban population density | Municipalities | |
| Am | low | 198 | |
| Am | high | 62 | |
| Af | low | 94 | |
| Af | high | 40 | |
| Aw | low | 716 | |
| Aw | high | 219 | |
| As | low | 400 | |
| As | high | 125 | |
| BSh | low | 225 | |
| BSh | high | 46 | |
| Cwb | low | 227 | |
| Cwb | high | 69 | |
| Cfa | low | 855 | |
| Cfa | high | 147 | |
| Cwa | low | 243 | |
| Cwa | high | 84 | |
| Cfb | low | 311 | |
| Cfb | high | 39 | |
| | | 4100 | |

| n_vars | V1 | V2 | V3 | V4 | V5 | V6 | V7 | V8 |
|---|---|---|---|---|---|---|---|---|
| estimate | aedes | ac_sw | idhm | pib_cap | ac_ws | ac_ww | gini | tfundin |
| aedes | 1 | 0,054937 | 0,195946 | 0,080517 | 0,576044 | 0,329354 | 0,116219 | -0,2092 |
| ac_sw | 0,054937 | 1 | -0,02251 | -0,01053 | 0,06615 | 0,066588 | 0,071407 | 0,005963 |
| idhm | 0,195946 | -0,02251 | 1 | 0,410676 | 0,1524 | 0,123942 | -0,31897 | -0,90031 |
| pib_cap | 0,080517 | -0,01053 | 0,410676 | 1 | 0,059989 | 0,035814 | -0,13251 | -0,42086 |
| ac_ws | 0,576044 | 0,06615 | 0,1524 | 0,059989 | 1 | 0,476458 | 0,116021 | -0,17349 |
| ac_ww | 0,329354 | 0,066588 | 0,123942 | 0,035814 | 0,476458 | 1 | 0,125769 | -0,18269 |
| gini | 0,116219 | 0,071407 | -0,31897 | -0,13251 | 0,116021 | 0,125769 | 1 | 0,324344 |
| tfundin | -0,2092 | 0,005963 | -0,90031 | -0,42086 | -0,17349 | -0,18269 | 0,324344 | 1 |
| p-value | aedes | ac_sw | idhm | pib_cap | ac_ws | ac_ww | gini | tfundin |
| aedes | | 0,000433 | 0 | 2,44E-07 | 0 | 0 | 8,35E-14 | 0 |
| ac_sw | 0,000433 | | 0,149613 | 0,500433 | 2,24E-05 | 1,98E-05 | 4,72E-06 | 0,702698 |
| idhm | 0 | 0,149613 | | 0 | 0 | 1,78E-15 | 0 | 0 |
| pib_cap | 2,44E-07 | 0,500433 | 0 | | 0,000121 | 0,021835 | 0 | 0 |
| ac_ws | 0 | 2,24E-05 | 0 | 0,000121 | | 0 | 9,19E-14 | 0 |
| ac_ww | 0 | 1,98E-05 | 1,78E-15 | 0,021835 | 0 | | 6,66E-16 | 0 |
| gini | 8,35E-14 | 4,72E-06 | 0 | 0 | 9,19E-14 | 6,66E-16 | | 0 |
| tfundin | 0 | 0,702698 | 0 | 0 | 0 | 0 | 0 | |

Example of correlation matrix

# E Appendix to Chapter 7 – Article published in Sustainability - 2022

Stormwater Utilities: A Sustainable Answer to Many Questions - Sustainability 2022, 14, 6179. https://doi.org/10.3390/su14106179

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Abstract: One of the most complex and difficult questions to answer concerns how to organize and economically support public services of all kinds. In terms of services that involve a multiplicity of actors and objectives, as is the case with urban stormwater management, the difficulty is magnified and resources never seem to be sufficient. This paper reviews the successful approaches to stormwater management in a number of countries and concludes that it is both feasible and possible to successfully structure stormwater management in cities using a variety of models and incentives. With examples from cases practiced in the USA and Canada, based theoretically on the user-pays principle and on the fair distribution of impacts, the text innovates showing not only a technically and legally viable option, but an opportunity for users to become aware of the importance of reducing environmental impacts. By raising the possibility of delivering services out of the general public budget, reducing the taxation of all in exchange for charging only users and improving the performance, the discussion is directed, in an innovative way, to a very rarely questioned aspect and links the change in mentality from and economic way of thinking towards the new stormwater paradigm shift and SDGs.

Keywords: drainage; fees; financing; stormwater management; sustainability; utilities

Accepted: 11 May 2022

Published: 19 May 2022

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## 1. Introduction

The management of urban stormwater evolved with the understanding of its role and the good and bad characteristics that such water brings to society. In each era, water has had different roles, but has always been connected with human activities, and cities were born and developed in close relationship with water. The close presence of water, whether for agriculture, energy production, navigation or consumption, in most cases brought value to the territories, with the exception of urban flooding [1].

Cities continued to grow and man thought wastewater and stormwater were reasons for diseases, and that it was necessary to take it as soon as possible to rivers, lakes, estuaries and the sea. The function of the receiving water bodies was not only transport, but effluent discharge, without treatment, as is still the case in many places today. In the era of 'tout l'égout' [2], the hygienist phase of the 19th century, the reigning order indicated was to move waste and rainwater away from the cities as quickly as possible, not only to avoid the proliferation of diseases, but also to prevent flooding. The concern was fundamentally hydraulic, with a focus on quantities and mass flows, i.e., the problem was reduced to the sizing of pipes and channels, a matter for engineers. Concerning stormwater drainage, there was an understanding that these were of good quality and free of pollutants [3], reinforcing the idea that only volumes, mass flows, and dilution should be addressed. As for quality, represented by pollution, people said that it was only a matter of diluting polluted volumes into larger volumes, free of pollutants. The issue of sizing structures for drainage and dilution went through the discovery of which rains could be predictable in each region, a problem of hydrology and statistics, the latter helping by informing the probability of occurrence of certain volumes and the associated risks, expressed by determining the so-called return times of the events. Again, problems and issues are more related to engineers. From the possession of this information, the problem of the decision to choose return periods, or "project rainfall", depended on political decisions, closely linked to investments to be made in physical infrastructure and their respective risks.

With the advances brought by microbiology and epidemiology and Koch's discoveries regarding cholera, the understanding grew that the issue of wastewater quality was of crucial importance allowing sanitary approaches to sanitation and drainage to occupy a prominent place; it was the beginning of the sanitarian phase after the hygienist phase of the 19th century. The first wastewater treatment plants started to be developed at the turn of the century [4]. The decision about the type of treatment and size of the facilities involved the determination of the desired quality levels for effluents, an issue that no longer affected only engineers, but also health professionals, considering the risks that society would be willing to undergo and the alternatives of investments to be made, i.e., again, decisions of a political nature.

Currently, as of the nineties, there is an upsurge in urban flooding problems for several reasons, with two of them more relevant and interconnected: demographic growth, with the consequent territorial expansion of the urban fabric; and climate change, leading to the perception that just draining downstream, ever further and with greater volumes, treating rainwater effluents in a concentrated manner, at the point of discharge ("end of pipe"), in a vision on the one hand hydraulic and on the other hygienist, has not even found physical spaces for the task [5].

Later on, simultaneously with the environmental and right to the city movements, the vision of sustainability took over urban environments that started to understand water not as a problem anymore, but as a solution to old and new issues of quantity and quality, such as scarcity, well-being and comfort, exemplified, respectively, by its use in daily life, embellishment and the fight against "heat islands" [6].

According to this approach, alternative techniques emerge, in opposition to the traditional method of removal, which mainly uses buried pipes. The new mentality is one of harmonious coexistence with water; therefore, in addition to its visible presence on the surface, there must be treatment at the source, that is, as close as possible to the places of origin, where precipitation occurs [7].

In terms of management, what worked before—the centralized management with command and control concentrated in the public power—requires changes, and a change in the traditional management paradigm. With new and multiple actors assuming different roles, disputing and sharing the resource represented by urban stormwater, practices are gradually changing and favoring the decentralization and democratization of decisions [8].

At the same time, the change reaches aspects of service funding, as the understanding had always been that flooding issues, linked to large volumes and flows (hydraulics), were usually borne, at great expense, by general (centralized) public budgets. The feasibility of solutions at the source, or located where precipitation occurs, generally requires potentially lower and decentralized expenditures enabling private sharing and participation in the solution in a distributed manner [9].

Around the world, this paradigm shift is being studied to create the best format for financing and management. The USA and Canada, countries where there have been successful experiences for some time (around three decades [10]), materialized through stormwater programs, are partially or totally based on the collection of tariffs from users. Users became important and stable sources of funds, specifically for the improvement in urban stormwater management systems to comply with legislation. In the USA and Canada, the collection mechanisms for funding the activity are called stormwater utilities (SWUs), with specific characteristics in each place, but which deserve to be observed in order to learn from them.

The contributions of this paper lie in the approach to a subject absent from the literature, despite its importance, exemplified by the number of existing cases and of importance of the countries in which it is presented. Despite this, however, SWUs are financing stormwater management mechanisms that are little used in most countries where funding is required. In this sense, the contribution is to expand the dissemination and discussions around the subject and its application, so that through its knowledge its use subject and its application, so that through its knowledge its use can be expanded and the can be expanded and the improvement in stormwater management can be achieved. improvement in stormwater management can be achieved.

Besides this short introduction, the article is structured in four more sections. The Section 2 will focus on issues related to the origin and reason for the emergence of SWUs. In the Section 3, several cases where SWUs exist are presented; in the Section 4 the results and discussions are briefly presented; finally, in Section 5, the conclusions are drawn. Figure 1 presents a flow chart of the study with each chapter, its main aspects, as well as some presents a flow chart of the study with each chapter, its main aspects, as well as some of its interconnections.

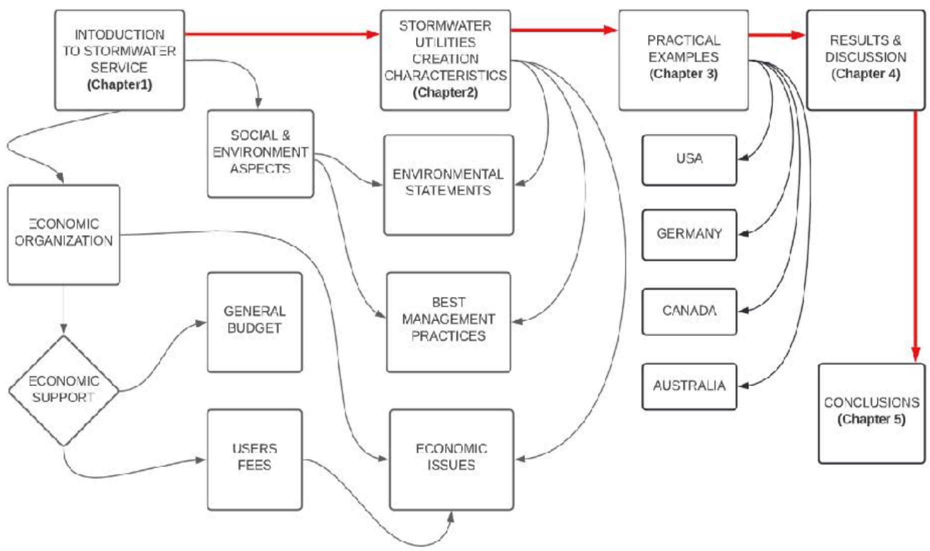


Figure 1 - Study flow chart.

2. The Creation of SWUs

In line with the diversity of aspects to be addressed, new demands for resources and management have arisen from the entry into force of legislation and regulations management have arisen targeted at improving the quality of urban service delivery systems, including stormwater management. Costs expected to result from climate change (increased frequency, intensity, and duration of rainfall with flooding and rising sea levels) have led to a search for alternatives to system funding through the application of the user-pays principle, based on charges levied on users according to their contribution to runoff, supporting, even if sometimes only partially, the new costs to be assimilated by budgets [11]. In each location, these financing methods, often associated with new management practices, have become financing methods, often associated with new management practices, have become institutionalized and have been given different names: SWU, stormwater fee, stormwater user fee, and stormwater service fee [12].

Cities support increasing costs, but with no proportionally crescent budgets, of maintenance and replacement of ageing infrastructure, of the new built areas and of quality and quantity costs occurring depending on climate change. In Canada, due to climate the stormwater infrastructure is considered in critical condition, but it was built in the last twenty years. With an estimated lifetime of 70–100 years for linear systems, 50–80 years for structures, and 25 years for electrical and mechanical components, this picture is surprising.

The SWUs, mechanisms to obtain resources for financing urban stormwater management, resulted from the perception by the American municipalities of the need to find economic means to cope with the increasing pressure on their budgets to meet socio-economic and environmental demands. These demands were incorporated into the American legislation through water quality control requirements due to diffuse urban stormwater pollution, considered a pollution point source at the point of discharge.

The legal and regulatory framework was developed over the last five decades since 1972, with the Clean Water Act (CWA) aimed at controlling water quality, revised in 1987 through the Water Quality Act (WQA), with provisions added for five categories of stormwater discharge. These provisions, classified under Phase I, established a set of restrictions for large and medium-sized municipal storm sewer separator systems (MS4). These systems cover populations greater than 100,000 and according to discharge quality permits, bring them into compliance with the National Pollutant Discharge Elimination System (NPDES). In 1990, the final rules were established for Phase I, and later, in 1999, for Phase II. In small MS4, in addition to systems for fewer than 100,000 inhabitants, there are industries and construction areas of 4047 to 20,234 m2 (1–5 acres). Stormwater eventually carries pollutants such as nutrients, pathogens, sediment, and metals, but must fall within the limits of the Total Maximum Daily Load (TMDL), a pollutant load that can be discharged to a given receiving body, without failing to meet the quality standards established by the states. The TMDL program applies to all MS4 systems, industrial and construction activities, and its limits include both point source and diffuse source loads [13].

Additionally, from the 1980s onwards, partly as a reflection of the taxpayer revolts of the 1970s, and the passage, in 1978, of proposition 13 in California, which placed limits on property taxation, some governments began to consider tariffs as a better source of resources than taxation for urban services. Thus, more favorable conditions were created for the introduction of stormwater utilities, a period considered as the utility model different from the traditional tax-supported public works model, until then predominant [14].

The creation of SWUs in the USA is not mandatory and depends on the perception of their need by the populations, policymakers, and those in charge of state legislations, on which SWUs depend to be implemented. There is no pre-defined size, with small communities such as Indian Creek Village in Florida (only 88 people), according to the 2010 Census population, and Los Angeles (over 4 million inhabitants).

There are nine models for calculating collection rates: dual, flat, tier, square foot, parcel acre, meter, usage, equivalent residential unit (ERU), and residential equivalent factor (REF). Some are based on impervious areas, such as the most widely used, ERU. Others are based on runoff generated, such as REF, or other forms of measurement. ERU is more popular in places with high population density and high property values while flat fee is more popular in places with low population densities and low property values [12].

Thus, in the absence of a general rule, the junction of necessity and opportunity has favored the creation of SWUs. The opportunity often occurred after catastrophic events, such as the hurricanes Katrina, in Louisiana (LA) and Mississippi (MS) fifteen years ago, and Sandy, in Connecticut (CT), New Jersey (NJ), and New York (NY) eight years ago, after which, however, by 2021, there were still no SWUs in place.

In the USA, the coming into force of legislation showed a relationship with the higher number of deployed SWUs [12], as also a clear definition of the legal authority in charge of each city, county, and watershed. In some way, important was the key role played by the professional organizations, providing information, support, and encouragement to communities interested in the implementation of SWUs.

## 3. Stormwater Utilities (SWUs)

### 3.1. The USA

In the US, according to research by the University of Kentucky, there are 1851 distributed SWUs identified, in 41 states and the District of Columbia [15]. While the number of SWUs may seem large, it becomes small when compared to the number of 22,389 communities computed as participants in the National Flood Insurance Program (NFIP), as of June 2019, meaning there are SWUs in less than 10% of this total. Despite a long history of SWU implementation in the US, the main challenges that remain for communities, regardless of their size, are related to adequacy of funding and public support, which are compounded by aging infrastructure [16].

The national average monthly fee paid by single-family homes is USD 5.94, increasing over time according to the consumer price index (CPI), with values varying from USD 0 to 45, although there are situations where reductions may occur and the range may reflect stormwater needs and also political contexts. The most widely used calculation method is based on the impervious areas of the land and on the ERU system, an average of the single-family residential impervious areas of land, but in some communities, a value can be defined based on the average of all the areas of residential land. The method calculates the amount to be charged based on the impervious areas of the lots, regardless of the total areas. The ERU is calculated through sampling carried out through field research [17], but can also be estimated through aerial or satellite images. Once the total impervious area of residential properties (AI) is obtained, it is divided by the number of properties, giving the ERU value [15].

For non-residential land, the rates are proportional to the ratio of the impervious area of the land to the ERU. The most commonly found average size for ERUs (895 utilities) in the University of Kentucky survey was 3072 square feet of impervious area, so it is important to determine ERUs accurately so that no one pays a disproportionate amount. There are other taxation systems, such as tiered systems (254 utilities) or flat fees (230 utilities). The ERU can be considered a system of infinite levels or steps and the flat fee and dual fee (108 utilities) as systems of a single level or step, the latter considering taxation for residences and another one for non-residential properties.

An example, taken from research conducted in 2021 by the University of Kentucky (Campbell, and Bradshaw 2021) [16], illustrates calculation systematics for a hypothetical area and allows conclusions to be drawn: residential waterproofed area = 15 107 sq ft; non-residential waterproofed area = 15 107 sq ft; ascertained ERU = 3000 sq ft; annual amount required for the selected level of service = CD$ 12 million and every household pays a fee of 1ERU.

Dividing the total waterproofed area (30 107 sq ft) by the standard computed ERU gives a number of 100,000 ERUs, 50% of which are residential areas and 50% of which are non-residential areas; therefore, a monthly fee of CD$ 1 million is required, which when divided by the number of 100,000 ERUs indicates a base amount of CD$ 10 per ERU per month.

If, however, for example for political reasons, it is decided that the assessed value to be used for non-residential areas should be for standard ERUs with 4000 sq ft and not 3000 sq ft, the number of non-residential ERUs becomes no longer 50,000 but 37,500 (1.5 107 sq ft divided by 4000 sq ft), totalling no longer 100,000 but 87,500 ERUs in the municipality (50,000 residential and 3700 non-residential), which implies a value no longer of CD$ 10/ERU, but of CD$ 11.43 per ERU (87,500 11.43 = CD$ 1 million per month) and, according to the following Equations (1) and (2), the percentage of costs will no longer be 50% between residential and non-residential areas, but 57% for residential and 43% for non-residential.

$$\text{Fracres} = \text{ERUres}/\text{ERUsres} + \text{IAnonres}/\text{ERU used} \qquad (1)$$

$$\text{Fracnonres} = 1 - \text{Fracres} \qquad (2)$$

Where Fracres corresponds to the fraction of the stormwater program paid by residential customers; ERUres is the total number of residential ERUs in the city; IAnonres is related to the total non-residential impervious areas in town; ERU used is the actual ERU used as opposed to the true ERU.

Similarly, if the standard ERU in the non-residential area with the value of 2000 sq ft is used, 125,000 ERUs will be obtained (50,000 residential and 75,000 non-residential), whereby the value of the ERU equals CD$ 8 (125,000 8 = 1 million) with the residential area bearing 40 and the non-residential area bearing 60% of the costs. Similarly, for ERU = 1000 sq ft, the percentages of monthly costs borne become 25% for residential areas and 75% for non-residential areas, or for ERU = 5000 sq ft, 62.5% for residential and 37.5% for non-residential users, respectively, according to Equations (1) and (2). From this, it is clear that the determination of the ERU is a very important aspect to have a fair taxation system that reduces the possibility of questioning.

Still, as to the example, it should be highlighted that it does not take into account possible reductions, applied in some municipalities, due to the placement of rainfall retention devices on lots or even the disconnection from collective drainage systems, besides other aspects that motivate exemptions.

The second most popular model is the REF method, with 133 utility cases; this system is based on the amount of runoff from a unit compared to the amount of runoff by a standard property of a single-family dwelling, considering an event with a determined return time, for example, 2 years and 24 h of rain, calculated by the rational method or the Soil Conservation Service (SCS). Besides relying on hydrological information over time and soils, this system penalizes commercial properties for shorter return times and residential properties for large return times [18].

Thus, building a model for calculating fair taxation, making SWUs accepted by all as a development factor, is still a complex and evolving task that depends on several parameters in addition to policy options in each location and different development context. Nevertheless, some SWUs have made significant capital investments through user fee programs, such as in Fort Collins (CD$ 120 million), Bremerton (CD$ 55 million), and Raleigh (CD$ 100 million), initiated in 1980, 1994, and 2004, respectively, and in the second case the investment is to promote the separation of the existing unitary system [16].

In 2021, most of the 73 participants in the survey, which covered 20 American states, conducted by the consulting firm Black & Veatch, declared to: have a separating system (82%); have a municipality as their area of jurisdiction (97%); carry out the collection of drainage fees on water and sewerage bills (78%); consider a drainage website the most effective means of ensuring approval and support for the fees charged to users; and to fit into Phase II (population under 100,000) of the EPA's Municipal Separate Storm Sewer Systems (MS4s) discharge regulation program.

EPA has 855 participants in Phase I MS4s (population over 100,000) and 6695 in Phase II MS4s which include many cities and regions. In the majority, i.e., in 54% of those locations, where combined systems still exist, the combined systems account for less than 25% of the total system. Despite being the third most important item cited in the survey and that 73% of systems have—according to the survey—aging drainage infrastructure, asset management plans are in place in only 63% of systems falling under MS4s Phase I and 35% falling under MS4s Phase II.

The main percentages of instruments used for funding corresponds to cash (78%) or debts (22%), according to the percentages of answers for each type of instrument. As for the main sources of revenue, 95% of the answers indicate that more than 75% of the amounts are supported by fees received from users and the three main activities described as included in the O&M budget are: illicit discharge detection and elimination (96%), best management practices (90-92%) and public education (92%) [16].

### 3.2. Germany

In Germany, in several cities since the 1990s, based on the polluter-pays principle, stormwater management charges have been introduced taking into account the impervious area. Since many cities have single systems, i.e., systems that deal with both stormwater and wastewater systems, they are charged jointly through a single fee and the calculation is based on water supply consumption, which is not a fair way of charging. From the idea of changing to a fairer system, based on the mentioned principle, in most states the fee for impervious areas was introduced, but just with a value around only 20–75% of the costs of stormwater and wastewater management [17].

There are two ways to calculate the impervious area: by estimation, according to zoning (Munich, since 1970), or by measurement (Hamburg, since 2012; Dresden, since 1998; and the State of Baden-Wuerttemberg, since 2010). Calculation by estimation is easier to implement but more inaccurate.

The implementation of the levy resulted in: waterproofing area reductions of 4.5 M m2 or 240,000 m2/year in Munich with 3000 ML groundwater recharge; 10% reduction in waterproofing area per person in Dresden; and in the state of Baden-Wuerttemberg, 48% of the cities reported decreases, 11% with high reductions already in the first two years after the levy implementation.

In Munich, maps with colours identify the runoff coefficients, being 0.9 for the blue zone, in the city centre; 0.6 for the pink strips, in intermediate regions, between the center and the outskirts; 0.5 for the outer suburban areas (orange); and 0.35 for residential plots in the outer suburbs (green) (Vietz et al. 2018). Additionally, several beneficial effects were noted, such as the reduction in the quantities treated in the combined systems in Munich and Dresden, enabling process optimization and deferring infrastructure upgrades of existing systems [17].

3.3. Canada

In Canada, only 4 out of 48 utilities use the ERU system and eight use property value or “ad valorem” taxation and the average taxation is CD$ 10.67 [15].

In the Victoria Community, located in British Columbia, integration between stormwater management (SWM) and street sweeping has recently been discussed with the latter usually being included in property-related fees [19].In Victoria, stormwater bills are issued annually to property owners and are deter-mined based on property-specific characteristics such as impervious areas (roofs, car parks, and driveways) measured with the aid of building plans, aerial photography and mapping using georeferencing technology (GIS).

The value, in 2022, is of CD$ 0.654 per square meter and street cleaning is determined by frontage length and street type, charged per meter of lot frontage, varying according to Table 1 below.

The property impact on the stormwater system through a flat portion of the charge, based on the building code is: low density residential—CD$ 0; multi-family residential— CD$ 81.79; civic/institutional—CD$ 72.98, and commercial/industrial—CD$ 148.38. Finally, there is a program in which property can be registered if they have ten or more parking spaces and are self-businesses, recreational facilities, recycling operations, storage yards, or have construction activities on site, paying CD$ 169.70 per year (2022).

Table 1 - Victoria charge, according to the type of street

| Street Type | meter of Street Frontage |
|---|---|
| Local streets | 1.81 |
| Collector streets | 3.84 |
| Arterial streets | 4.35 |
| Downtown streets | 43.60 |

In a study conducted in the City of Thunder Bay, comparing the various forms of taxation for stormwater funding, the conclusions were that urban properties subsidize rural areas by approximately CD$ 300.00 annually and that residential properties account for 67% of the contributions to the stormwater program while non-residential properties receive the remaining 33%.

However, the runoff from residential areas is only 58% and the remaining 42% comes from non-residential areas, meaning that a distribution based on contributing areas would lead to a 9% redistribution, i.e., the average residential properties would bear 9% less while the non-residential areas would bear an average of 9% more in levies.

Although this distribution would be fairer, one of the recommendations of the study was that the change would only be worthwhile above 10%, given the high implementation costs of reallocating only CD$ 360,000 per year from residential to non-residential plots, against a budget of CD$ 4 M and minimal apportionment of the difference among the 38,203 existing residential properties.

There are, however, other aspects that should be considered in the long term, such as the observation that property tax encourages urban sprawl while the user fee option encourages densification, and other issues including environmental liabilities [20].

3.4. Stormwater Management in Australia

The changes that occurred in water management in Australia over the past five decades determined its current state, according to a path dependence viewpoint (Otoch et al. 2019) [21].

However, according to Brown and other scholars, moments of tension and alignment existed between six distinct institutional logics (decision making, risk, sustainability, water quality, infrastructure, and demand) that coexisted in permanent evolution. Thus, according to a study conducted in the period between 1970 and 2015, throughout all that time, the urban water management sector in Australia showed great complexity [22].

In this context, the evolution (rather than a revolution) towards the current practices of Sustainable Urban Water Management (SUWM), which emerged in the 1990s, was based on the trajectory travelled by the logic of sustainability, water quality, and demand.

Changes in the idea of sustainability were characterized by the focus on aquatic health and the reorientation of the vision of point source pollution to diffuse, reflected in the logic of water quality that has become more restrictive with standards and monitoring based on aquatic ecology.

The demand was characterized by the emancipation of the end-user and the growth of expectations related to urban amenities and environmental protection. The infrastructure model, identified with engineering expertise, evolved from civil engineering based on fore-casting and control to a more significant multidisciplinary approach, in which adaptability and flexibility became important design parameters.

The decision-making logic also evolved from the seventies, when it was characterized by bureaucratic, paternalistic decisions, centralized in powerful, vertically integrated organizations, and focused only on water supply, treatment, and drainage.

As of the 1980s, the government's influence grew, with the private sector participating and the predominance of the economic efficiency viewpoint. Decisions considered economic factors first, causing the user-pays principle to take the place of the tenure principle, which had property as the determining value in pricing decisions.

As of the 1990s, this vision intensified, reflecting free-market competition, with a commercial focus and financial instruments in decision-making. Public–private partnerships, for instance, are considered an alternative, and the user acquires the status of a consumer.

This framework remains from the 2000s with the water markets [23] when, however, due to the "millennium drought" at "a critical juncture", according to the definition of historical institutionalism [24], the logic of risk comes into play, temporarily interrupting decentralization, and the construction of large centralized desalination structures in all major cities [22].

Australia has a federative system of government, commonly referred to as "Common-wealth" or federal, with six states, two territories, a constitution, proclaimed in 1901, which defines the roles of each of the eight federal entities and, according to section 100, water management is the responsibility of each.

In the states and territories, there is another level of local government, which are the municipalities and district councils. In most states, the state governments own the utilities and local governments do the planning and management of stormwater services and the systems are separative.

For over thirty years, Australia has been developing its national water quality management strategy. It includes the use of stormwater for supply and guidelines are available for adoption by the states and territories. There are also guidelines for the evaluation of Water-Sensitive Urban Design (WSUD) options that incorporate an integrated approach to the urban water cycle. This includes the management of water supply, sewerage, groundwater, stormwater, land use, and environmental protection.

3.4.1. The Salisbury Example—South Australia

The city of Salisbury, in the metropolitan area of Adelaide (population 1.3 M), South Australia, developed through rapid urbanization from the 1970s onwards. Today, with around 137,000 inhabitants and an average annual rainfall of around 430 mm, mostly occurring in winter, it adopted WSUD principles to maximize the use of run-off water and reduce the risk of flooding. Aquifer recharge management was introduced to control the low salinity of stormwater by using Aquifer Storage and Recovery (ASR) in a brackish aquifer for subsequent irrigation.

The stormwater is collected in retention basins forming wetlands and lakes and subsequently infiltrated into the aquifers, with retention time around seven to ten days, being recovered through ASRs or Aquifer Storage Transfer and Recovery (ASTRs) allowing the reduction in the demand for water supply used for irrigation of sports fields.

Wetlands now occupy about 200 ha of the catchment area and in 2001 the City of Salisbury expanded the use of urban stormwater as a commercial enterprise through a public–private partnership project. The project focuses on applying AUD 4.5 million to construct wetlands and ASR facilities for stormwater treatment and storage, at Parafield Airport, a secondary airport in Adelaide. In this case, also a purple pipe network was constructed for the Mawson Lakes neighborhood, with recycled water comprised of a combination of stormwater from the Parafield Airport wetlands and wastewater from the Bolivar Sewage Treatment Plant.

The success of this operation led to the formation of a pioneering business that included nine projects in different locations. Providing non-potable water in a volume equal to 5 106 m3 per year showed that stormwater containing contaminants, when stored underground and under control, can be used for uses such as irrigation of public open spaces and, when chlorinated, can be supplied in pipes (third pipe supplies). Its use for potable purposes depends on the additional use of microfiltration, UV disinfection, and chlorination, but the costs of these additional operations to reach the required safety standards are considered to be lower than the costs of laying double distribution pipes. The total cost of supply (capital and operation), for example, in 2012/13 was AUD 1.57/m3 for non-potable use for irrigation of public spaces and AUD 1.96 to AUD 2.24/m3 for potable use (excluding distribution network costs), therefore cheaper than the usual AUD 3.45/m3 for mains water [25]. The costs of providing non-potable water through a new distribution network, however, are similar to or higher than the costs of distributing water from the existing network.

In 2010, a business unit, Salisbury Water Business Unit, participating in the administrative structure, administered by the SWMB and chaired by an external independent member, was established. The unit manages various water collection and supply schemes for non-potable use, being mainly recycled rainwater and native groundwater. Treated to standards, according to the purposes for which they are intended, it is distributed to parks, reserves, schools, industries, and some residential sectors. It serves over 500 users, among them 31 schools, and generated AUD2.8 million in resources in 2015–2016.

3.4.2. Melbourne and Victoria

In Greater Melbourne, 5 million people live in an area of about 10,000 km2 with an average annual rainfall of around 600 mm [26]. There is a fixed annual charge per household, based on property value, which is paid as part of the Waterways and Drainage Charge, regardless of the amount of waterproofed area and the impact it has on drainage systems. In the Australian state of Victoria, the Water Act governs how the Waterways and Drainage Charge should be implemented, but it is unclear how the level of waterproofing may influence the levy.

The theoretical graph in Figure 2 demonstrates how the fixed charge works and allows a reflection on the greater possibilities for incentives for non-sealing that can exist from a variable charging policy [17], which is fairer, collects more resources to support the systems, and provides incentives to non-sealing and disconnection. These can alleviate the need for extensions and maintenance on stormwater system and save resources more efficiently. Charge, should be implemented, regardless of the amount of waterproofed area and the impact it has on drainage systems. In the Australian state of Victoria, the Water Act governs how the Waterways and Drainage Charge, but it is unclear how the level of water-proofing may influence the levy.

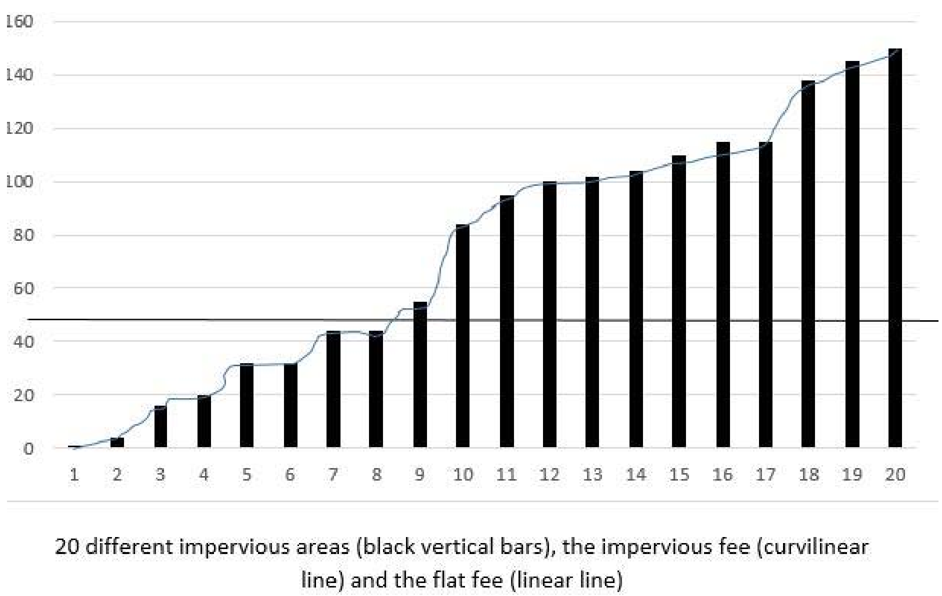


Figure 2 - Comparison between fixed and variable rates considering the same total storage for 20 dwellings with different degrees of waterproofing [17].

4. Results and Discussion

Unlike decades ago, when stormwater management was focused only on urban flooding, there was an evolution that, presents differences and similarities in developed and developing countries. The main issues involve multiple aspects and challenges such as water and environmental quality, aquifer recharge, supply and treatment, urban heat islands, urban well-being, street trees [27] aquatic life, landscaping, and leisure, and flood analysis [28], among many others users [29]. Although interrelationships between stormwater and wastewater are known, in several countries, especially where the absolute separator system is adopted, at least officially (as is the case for Brazil), management is still focused on wastewater treatment. This (as is the case for Brazil), management is still focused on wastewater treatment. This is partly due to the significant sanitation deficit [30], and so stormwater is erroneously partly due to the significant sanitation deficit [30], and so stormwater is erroneously considered allow priority, except when flooding events occur [19].

Thus, the collection of stormwater fees and the construction of management structures dedicated to urban stormwater management, with or without private sector participation, has been left behind, especially in developing countries. Initiatives for its implementation are the target of many objections, including judicial ones, as was the case in the municipality of Santo André, in the ABC Paulista, metropolitan region of São Paulo. After a period of evolution and success in the use of charging, started in 1998, a setback occurred, with its suspension in 2012 [31].

Experience, however, including in the U.S., has shown the importance of information and disclosure, particularly when on user demand, with the most used channel of communication with the public being the website [16]. The Web aims at the understanding, involvement, and participation of society and the reduction in objections, proposed mainly by non-residential users. The objection questions are mainly of two types: the legality of the authority responsibility for issuing, implementing, and financing the fees and the legality of the charging mechanism [32].

The organization of management through SWUs considers the institutionalization of the application of fees as an economic support strategy for stormwater management. It is based on four criteria: efficiency, equity, adequacy, and feasibility in the collection and use of revenues. It enables long-term planning of capital and operational investments, brings the potential for change in public behavior, and impacts business and management of municipal investments, but at the same time suffers objections from users, including legal ones.

The tariffs, in general, are based on the operating, maintenance, and, when possible, the capital costs of the systems, distributing them among the users according to criteria that, in most cases, correspond to the waterproofed areas. The criteria seek equity not only through proportionality between tariffs and the contribution to runoff and pollution generated, as established by the user-pays principle, but through different payment capacities, expressed, for example, by property values or consumption of services such as water supply.

The issue of stormwater systems' economic support is still quite controversial, even in places such as the USA and Canada, where there are legal challenges, most of them being refused by the courts. Barriers to their implementation also exist, as can be seen in the Canadian example of the City of Thunder Bay, where the conclusion led to the option, even in the short term, of not adopting the fairest method of distributing the burden of waterproofing.

There are several ways of economic viabilization and funding stormwater management services, but they can be summarised in two, especially with regard to fundraising: the traditional model, based on the general budget (payment by all citizens), and the model based on payment just by the users of the service, known as the stormwater utility.

These two different visions on how to obtain resources to economic support public services are part of a larger dispute involving the role that governments should play in the solution of socio-economic-environmental problems. The traditional vision is opposed to the innovative vision of stormwater utilities, the latter responding in part to the population's desire for more fair tariffs and to reduce the burden of general taxes, as occurred in the USA decades ago, when stormwater utilities were implemented. However, decades after their implementation, the thought that they are hidden taxes disguised under another name still survives.

Existing experiences and those under implementation deserve to be observed, as well as examples extracted from them of what may work and what may not work so well in each context. However, there should be no delay, as this is still a subject that deserves practical experimentation, a kind of learning by doing, given the increasing demands that are coming with the growth in urbanization, rising temperatures, increased urban rainfall and rising sea levels, according to climate change forecasts.

For example, in Brazil, where the focus is still very much on the scarcity of public resources, the introduction of management and funding mechanisms such as SWU, based on the user-pays principle, can work. As in other countries, stormwater utilities in Brasil are welcome, as long as they are applied through policies that encourage not only the economic contribution of users, but that consider forms of management with focus on results. Besides that, they may lead to increasing the involvement and participation, bringing the contribution of all actors to the decisions made, including the design of the calculation methods of charging and the legislation. This may mean opening the way to solutions that lead to economic autonomy of stormwater services management and also for disengagement from the general public budget, decreasing taxes, with gains in responsibility distribution efficiency and a permanent flow of resources to the sector, providing sustained continuity to the actions.

The study shows that the use of the stormwater utilities mechanism is more developed in countries where environmental legislation has been fully implemented. Table 2 shows examples of the countries' main approaches, fee criteria and objectives. From the information in Table 2, although it is not possible to verify uniformity in all aspects, there is a trend in the approach to control environmental effects (reduce pollution of water bodies) and in the criteria for calculating tariffs (sealed areas).

However, there is no definite trend regarding the form of quantification of the objectives, a fact that can be attributed to the experience and reality in each location. From the perspective of the economic efficiency objective, information on collected revenues compared to measurable cost outcomes of avoided environmental impacts (e.g., volumes of treated effluent) can allow for the ranking of stormwater utilities initiatives. Measured economic parameters also enable the comparison with other alternatives such as the overall budget itself.

This is different in countries where there are no legislation incentives or, as in Brazil, where the law has existed for a long time and is broad, but encounters obstacles to application. Utilities with a low level of institutionalization and administrative and economical disorganization tend to relegate environmental issues, postpone the acquisition of economic support and, eventually, adopt the funding and organization structure.

Table 2 - Countries, approaches, fee criteria and objectives.

| **Country** | **Main Approach** | **Practical Fee Measures Criteria** | **Objective's Evaluation Metrics** |
|---|---|---|---|
| EUA | Environment Pollution Conttrol | ERU ($m^2$ of impervious areas); many others (flows, etc) | Pollution & environment statements attendance |
| Germany | Environment and Equity Polluter-Pays Principle | Impervious area and water supply consumption | Impermeable surface reductions, groundwater recharge and treated quantitative vol. reduction |
| Canada | Polluter-Pays Principle | ERU ($m^2$ of impervious area) and "ad valorem" property tax | Impermeable surface reductions |
| Australia | UWM—Sustainability Urban Water Management | Fix based on property values) | Groundwater recharge Measurements; stormwater and reuse of non-potable supply |
| Brasil | Flow Control | $m^2$ of impervious area | Undecided |

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## Conclusions

The overview of SWUs presented here provides an update on what has been implemented to ensure the economic sustainability of urban stormwater management systems with the participation not only of the public sector but also of users and private agents, being remunerated as a public service to society as a whole.

The study's contribution comes in the sense of bringing together scattered information and thus allowing the formation of a general picture of the evolution in a certain direction, namely, the economic organization and financial sustainability of urban stormwater drainage and management under a new paradigm, which has been occurring simultaneously in several places around the world.

The perception of this fact as a general trend does more by allowing scholars, re-searchers, and practitioners to identify it and become aware of what is still missing for its rapid institutionalization, implementation, and experimentation, thus contributing to the evolution and improvement in the sector's actions. This is a small contribution, given what still needs to be done, but with the potential to help transform the reigning mentality, or the business as usual, and in this sense it can be significant.

The institutionalization of charging users for the provision of urban stormwater management services, whether provided by public or private operators, always encounters obstacles, posed by those who believe that they should be compulsorily provided by the public authority and funded by general public budgets, which means the cost is socialized for all the society. Either due to technical reasons, such as methods of quantification of the shares that each one is responsible for (the user-/polluter-pays principle), or to issues of understanding regarding the services to be provided by the state or for various legal and rights-based reasons (i.e., legal, among others), the fact is that barriers exist to the implementation concept of stormwater utilities.

The reality, however, has shown that in several countries there are feasible ways of charging equitably for the services, relieving public budgets, encouraging the reduction in impervious areas and the disconnection to urban stormwater systems, i.e., saving nature from impacts, taxpayers from unfair costs, and public budgets from unplanned expenses, made to remedy sudden failures after extreme precipitation events, which are increasingly frequent due to the climate.

Based on theoretical knowledge, expressed in various pricing and collection formulas that have been tried in practice in different countries, it is possible to see that economic sustainability, as the economic side of the ongoing paradigm shift in urban stormwater management services already has feasible options and alternatives. Thus, the argument that urban drainage is a public service left "for later" due to a lack of resources or economic organization does not hold. Political will can set in motion policies, institutions, and regulations that, aligned around the objective of solving drainage sector issues, set in motion incentives for economic organisation and financial support.

The novelty is the possibility to make the economic change a viable side of the stormwater paradigm shift, in a win–win manner, with more than economic gains for all actors. There are efficiency gains in terms of environmental, social, institutional, organizational, and political aspects.

This is not all, since society's acceptance of the paradigm shift, through the understanding of the gains that are thus produced, requires an effort of awareness. This is not only motivated by economic–financial gains and reasons, but by others of ideological nature, that is, at the level of ideas and ideals, as is the case for the sustainable development goals. SDG's are present in the paradigm shift, but are not always perceived and require more work from all. A missing economic aspect that is important in ascertaining the speed of the paradigm shift is the quantification of 'green' and 'grey' infrastructure investments made with the revenue raised through SWUs. This is an aspect for study, that is, it is important to know to what extent the mechanism and the collection from users has contributed to the implementation of more infrastructures that favor the paradigm change (e.g., green infrastructures) such as the quantity of street trees and many others leveraging the change. Criteria to measure the achievement of clear objectives make the possibilities of reaching them visible, contribute to adjustments, and can help everything run more quickly towards the change in paradigm.

The study explored the existing publications, information, and data to which it was possible to have access and, by adopting this methodology, it carries with it the limitations arising from it, such as the absence of information that does not exist in the databases studied, or even the form of research used in these bases. Additionally, given the dynamics of the temporal evolution of the experiments, they will continue to occur, often surpassing the ability to become aware of them and analyse them, a fact that is part of the research process.

Author Contributions: Conceptualization, C.N. and R.M.; methodology, C.N. and R.M.; validation, C.N. and R.M.; formal analysis, C.N. and R.M.; investigation, C.N.; resources, C.N. and R.M.; data curation, C.N.; writing—original draft preparation, C.N. and R.M.; writing—review and editing, C.N. and R.M.; visualization, C.N. and R.M.; supervision, R.M.; project administration, R.M.; funding acquisition, C.N. and R.M. All authors have read and agreed to the published version of the manuscript.

Funding: The authors are grateful for the Foundation for Science and Technology's support through funding UIDB/04625/2020 from the research unit CERIS.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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# F Appendix to Chapter 8 – Article published in Water – 2022

Attracting the Private Sector to Urban Stormwater: A Feasible Task or Just a Pipe Dream?

Water 2022, 14, 2164. https://doi.org/10.3390/w14142164

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Abstract: Private sector participation (PSP) in stormwater drainage and management systems is desirable for two reasons: firstly, for its capacity to contribute resources, allowing existing public budgets to be used for other purposes, and secondly for its capacity to introduce management efficiency. Despite the apparent simplicity of this conceptualization, in practice, such participation does not occur simply out of a desire to improve service delivery. Private and public partners have their interests, which are, on the private side, the profit margins and deadlines for return on investments, and on the public side, representing society, the obligations of equity, universality, continuity, and the sustainability of service provision and infrastructure. Reconciling these often-contradictory aspects requires complex and sophisticated political, institutional, organizational and regulatory structures aligned to provide incentives, resources, and involves everyone. Without exhausting the subject, this article addresses several aspects related to the attractiveness and participation of private initiatives in urban stormwater management and discusses some international examples with a special focus on Brazil.

Keywords: public services; stormwater management; private participation; case study analysis

1. Introduction

An important aspect of the institutional arrangement of the water sector (WSS) is the different degrees of private sector participation (PSP) in the provision of the corresponding services and infrastructure [1]. Issues of cost, efficiency, and investment are usually arguments in favor of private participation in service delivery. Limitations on public budgets and greater management efficiency by the private sector, by its very nature, and objectives of cost recovery and return on investment, are part of this context. The existing public resource limitations added to aging existent infrastructures, climate, and demographic changes increase the necessity for investments, creating urgency in applying new sources.

In Brazil, the issue that bothers and mobilizes the actors around PSP, which to this day is very low in the country and tremendously low in stormwater management, is the low degree of inclusion or poor universality of the services and weak quality of the services provided. Without addressing other and diverse reasons for this poor performance, the debate has been restricted to questioning what types of providers could break this cursed logic that has resulted in 35 million people without access to water and over 100 million without access to sanitation services, with consequent impacts on the health and economy of Brazilians. The panorama in stormwater management is even worse [2]. If only the change in the origin of the capital invested and the execution of well-designed contracts between the municipalities and operators were sufficient to achieve universal access and the provision of quality services, everything would be solved the next day, but the reality is quite different and PSP, although it is welcome and should have coherently constructed contracts, requires much more than that, and provides challenges that must be gradually overcome, some of which are presented in this research.

In the case of urban drainage, due to its unique characteristics, the complexity brought about by its interrelationships with other sectors such as urban planning, health, and economy, and its low level of institutionalization, including possible economic and financial support through pricing, the design of PSP is a subject that requires intelligently creative and innovative solutions, with different local aspects that make defining its approach in a single text practically impossible.

Throughout the 1990s, PSP in the WSS was widely considered to be the solution to sectoral problems, specifically the lack of investment and inefficiency, but in the following decade, the vision changed due to several reasons, among them the insufficient engagement with finance in developing countries and the lack of clear conclusions about the benefits of this participation.

The World Bank emphasized in a 2003 Operations Evaluation Department report that: "Private Sector Participation (PSP) is not a panacea to deep-seated problems and cannot be expected to substitute for decisions that only have the power and obligation to make. PSP is better likened to a sharp tool. A capable government can use it to great advantage to improve the water supply and sanitation situation but an inept government can make worse through an injudicious use of PSP without providing clear quality and price regulation and lending strong and sustained support to PSP" [3].

Usually, the question of whether services are provided through public or private initiative takes second place, because the population primarily wants services to be subject to good performance, including their governance, which leads to expected good results through the execution of the objectives outlined by public policies and good decisions made by those responsible for them [4,5].

The relationship between political governance and WSS governance and performance aspects in the provision of services, such as the expansion of coverage and the efficiency of providers, should be analysed, as their impacts can be either positive or not. In political governance, institutions—as the main actors—shape the relationship between citizens and government actors (political rights and electoral systems) and the rules that determine government organization (separation of powers, checks, and balances), and in WSS governance the main aspects are institutions, borders, and coordination in the participation of actors. Institutions are the main elements of governance as they shape the behavior of the actors responsible for policy-making and policy decision-making. In WSS governance, in addition to the coordination between the actors responsible for policy-making, services provision, and regulation, the participation of users and the definition of boundaries between all actors are important [5].

In practice, the degree to which the existence of PSP has a positive contribution to the provision of the WSS depends on the overall country environment and institutional context [6]. In Chile, for example, before privatization, as public providers, there was a good quality of political governance and governance of the WSS [3]. There are examples of successes and failures of public and private participation (Buenos Aires, Paris, and Berlin) in a pendulum movement, depending on each context [7].

Europe, starting in the 1990s with the Urban Wastewater Collection and Treatment Directive (UWWD), following the concept of sustainability defined by the UN, added environmental, ethical, and equity costs to economic ones.

The so-called three E's—economics, environmentalism, and ethics and equity [8]—can be summarized in the form of questions posed by water policy analysts (EUROWATER partnerships):

If we do invest enough, what impact will this have on water bills? —Economic Issue

How much more should be raised to upgrade environmental performance? —Environmental Issue

If all sustainability costs are to be passed on to users, can they afford it, and is it politically acceptable? —Ethics and Equity Issue [8].

As one of the advantages listed for private participation (greater efficiency and flexibility in management and investment capacity), traditional costs are well known and Usually taken into account (full supply costs). However, with the discovery of other costs, hidden by the former, the new distribution of costs, as shown in Figure 1, including those impacted by a new distribution of risk between public and private participants, deserves to be reviewed to achieve the economic and financial sustainability of the WSS [9]. This sustainability could be achieved using equilibrium between costs and sustainable value in the use of water which should be equal to the full cost [10].

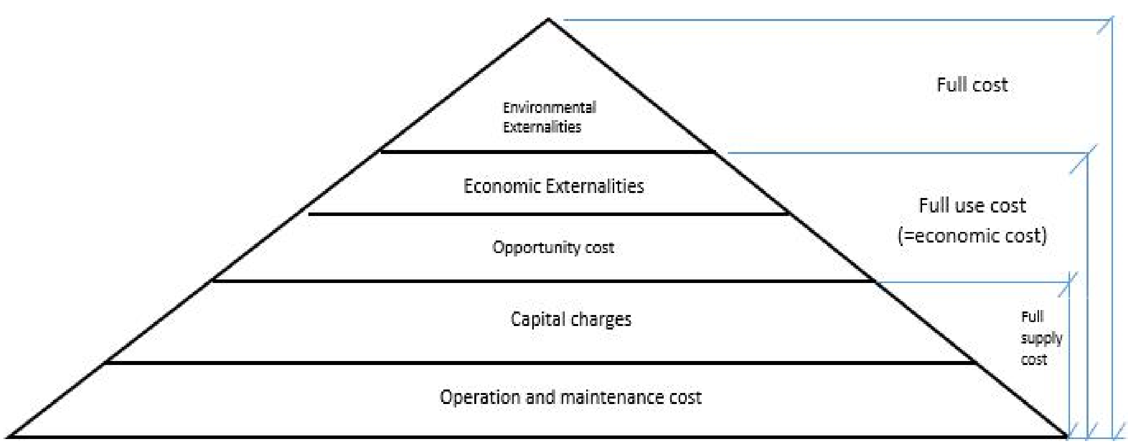

Figure 1 - Components of total cost (adapted from [10]).

The revisited new composition of the total cost parcels, to achieve economic and financial sustainability, must not only cover the determination of which portion should be borne by users – i.e., being collected by local governments, their concessions and partnerships, and through tariffs including subsidies – but also which portion should remain with all taxpayers, through taxes collected for the general budget of states.

Onsite stormwater treatment and use is an additional alternative to traditional systems, for example, with separate systems, one for stormwater runoff and the other for wastewater, or treatment combined systems. However, from the moment that stormwater started to be seen as a resource and was made available for potable and non-potable uses, a higher degree of complexity was added to the calculation of costs for each parcel, public or private, making the design of the financial and economic sustainability of urban stormwater management systems more complex than that of potable water supply and sanitary sewerage [11]. Furthermore, in most municipalities, there is no breakdown of costs, as they are practically unknown, which makes it difficult to calculate them for various purposes, including those related to possible contracting or partnerships with private entities.

In cities where economic sustainability is based, at least in part, on one of the three T's of the triple bottom line of service delivery systems – tariffs, taxes and transfers [12] – charging for urban stormwater management costs can be determined in several ways.

It can be calculated, for example, from the volume of water supplied, as is performed in many places for the costs of runoff and wastewater treatment systems, or based on estimates of the amount of surface area in each plot, as is the case with most stormwater utilities in USA and Canada [13]. Thus, methods are usually used to estimate the volume of runoff from lots considering, in addition to the area (total and sealed), infiltration factors, use (e.g., residential, commercial), property value and several other factors, or just by applying a fixed value not always linked to any specific parameter, but in general linked to operating and maintenance costs and sometimes necessary capital investments. The other types of costs – environmental, ethical, and equity – remain a challenge so far.

This article aims, through the discussion of case studies, to present some existing forms of private participation in the management of urban drainage services in different places—some of which are still under construction and in progress, but with potential for success—and to contribute to ongoing discussions, providing evolution for the subject and consequently for the sector. Particularly, it discusses the Brazilian case study, shedding light on the main issues and offering recommendations for PSP success.

The subject is organized into five sections in addition to this brief introduction. Section two deals with the attractiveness and efficiency of PSP. Sections 3 and 4 set out international and Brazilian experiences. Section 5 summarizes and discusses the results of international experiences, focusing on the Brazilian experience. Finally, Section 6 draws the main conclusions of the paper.

2. Attractiveness and Efficiency

In the private sector, the driver for attractiveness is the opportunity to monetize capital, while in the public sector, it is the search for the best service provision along with lower costs, and greater breadth and equity. Thus, attractiveness is linked to the costs involved, whether purely economic, environmental, or social.

Investment costs are more significant than maintenance costs; however, those related to flooding should be accounted for, even if under the heading of environmental expenses. For combined systems, which are still the majority (50% or more), the expense of overloading treatment facilities during flooding also deserves to be factored in.

Concerning efficiency, in the private sector, there are management standards represented by extensive voluntary standardization (e.g., ISO 9001 and ISO14001), and in the public sector, this is mostly achieved through regulatory requirements [14].

In Brazil, however, the absence of precise information on the demand for drainage services leads to cost estimates based on the calculation of average production costs, prioritizing the financing of the system and cost recovery, i.e., neglecting efficiency, since all expenses (necessary or not) are distributed by the customers of the services, which is a disadvantage in terms of not taking advantage of the capacity to produce efficiency in PSP. The option of estimating an average cost is considered a second-best solution, if compared to the alternatives of social marginal cost or cost according to marginal benefit that considers price–demand elasticities. One advantage of PSP in drainage is the possibility of rescuing the idea of efficiency in urban land use through the quantification of the costs involved in its sealing.

In PSP, there is a division or sharing of risks between the public and private sectors, as in the case of PPP arrangements, which have been extensively discussed, where the presence of guarantees provided by partners is intended to reduce risk; this is understood as the multiplication of the probability of occurrence by the magnitude of the impact caused if the risk in question were to occur. In the case of the participation of the private owners of the lots, through their reduction in flow or even their total disconnection, the costs of the devices implemented in the lot may be borne by the private owner or receive incentives such as a reduction in tariffs or subsidies for their implementation. It should be taken into account that there will always be centralized systems and that, therefore, not all actors should be encouraged to disconnect because the systems would stay without resources; that is, there is an ideal number of incentives for each location.

Another form of PSP is the partial or total privatization of companies belonging to public authorities, as is currently happening in Brazil, the most recent case being that of the Rio de Janeiro State Water and Wastewater Company (CEDAE), which was put up for public auction in which a concession was offered as payment to the state, but without any link to the application of resources in the sector. The company was granted a long-term concession through an extendable contract.

PSP can also be made by offering shares on the stock exchange, as in the case of the Companhia de Saneamento Básico do Estado de São Paulo (SABESP) which has shares in the

São Paulo and New York stock exchanges. In this case, an inconvenience concerns the profit distribution percentages that sometimes exceed the minimum stipulated in regulations. Thus, the reasons for not making investments to reach the universalization of services or to execute works to improve quality and resilience in times of scarcity are questioned. The participation of private capital through shares quoted in the market urges management to seek efficiency, as demonstrated through profitability with consequent valuation and attractive investments, but the balance between the necessary investments to serve the customers, the tariff affordability, the expansion of the operation, and the profits to be distributed using dividends to the shareholders require professional management. In this scope, drainage is left to the municipalities with no such participation in the market, requiring new, creative, and attractive solutions that sensitize the actors with potential interest.

Finally, an important factor of attractiveness is the existence of public policies that favor PSP, such as flow reduction policies, because they signal a reduction in fixed expenses (with less construction and equipment) which, over time, generate a reduction in variable expenses for the operation and maintenance of these infrastructures, that is, a reduction in total costs. On the contrary, negligence in this area becomes very expensive because by not designing a policy to restrict the increased inflows, the growth of costs and eventually inefficiency is accepted with a possible reduction in attractiveness to PSP.

In addition to cost reduction policies, there are policies to increase revenues such as rainwater reuse or utilization policies, which are considered policies that increase the attractiveness of PSP.

The use of the analysis tool based on the SWOT matrix, originally developed for strategic business and marketing planning, but also used in participatory planning [15] can be adopted for checking possible scenarios and policies for PSP in stormwater. Based on internal factors (strengths and weaknesses) and external factors (threats and opportunities), prospective scenarios are elaborated from combinations of these factors. The combination of (internal) strengths with (external) opportunities produces a first, so-called aggressive, or maxi–max scenario in which strengths and opportunities are maximized. A second scenario in which the weaknesses (internal) are combined with the opportunities (external) produces a conservative or mini–max strategy, in which the maximized opportunities (external) must compensate for the weaknesses (internal) that are aimed to be minimized. In the third scenario, the strategy, called competitive, or maxi–min, the strengths (internal) and the threats (external) are combined and, in this scenario, the management of the strengths seeks to avoid the materialization of the threats. Finally, the combination of weaknesses (internal) and threats (external) produces a defensive strategy, or mini–mini, which seeks to minimize both weaknesses and threats [16].

Without exhausting all of the aspects present in PSP in stormwater management, just as an example, we produced a SWOT matrix according to Figure 2 below.

An example of a max–max aggressive strategy of forces and opportunities could be the design of a policy to encourage the use of rainwater as a resource (external opportunity) and the intense use of private resources (internal strength) to finance storage devices on plots through incentives to the owners.

A second example of a conservative or min–maxi strategy can be seen through the use of a policy of publicizing stormwater utility (internal weakness) combined with the intensified construction of stormwater amenity sites such as retention basins (external opportunities).

The competitive or max–mini strategy (reinforcing internal strength), e.g., building works and equipment against floods and spreading preparedness for climate change and future uncertainties (external threat), is the third scenario.

The fourth scenario is defensive or mini–mini, can be exemplified by a policy of increasing the visibility of infrastructure (internal weaknesses) and fighting corruption (external threat).

| STRENGTHS (internal factors) | WEAKNESSES (internal factors) |
|---|---|
| Capital needs for WSS<br>Fear population flooding<br>More health and urban well-being<br>population demands<br>Urban demographic growth | Lack of dedicated budgets<br>Lack of knowledge staff<br>Lack of physical infrastructures<br>Low acceptance like a public service<br>Low visibility of services |
| **OPPORTUNITIES (external factors)** | **THREATHS (external factors)** |
| Control of heat islands<br>Creation of new infrastructure<br>Diffuse pollution control<br>Implementation of amenities<br>Optimisation of existing infrastructures<br>Rainwater/Stormwater as a resource | Climatic changes<br>Corruption<br>Discontinuity of administration<br>Economic unfeasibility risks<br>General and local legislative gaps<br>Lack commitment of political decision makers<br>Lack of specific accounting<br>Lack of understanding of society<br>Unpredictability of the future |

Figure 2 - SWOT matrix for stormwater PSP**.**

3. International Private Participation

In this section, the experience of PSP in the water sector and, particularly, in stormwater management is presented for six countries. Cases studies of the USA, China, Portugal, Argentina, Germany, and Australia are discussed and the main lessons are displayed. The next section will focus on the Brazilian experience.

### 3.1. USA—Stormwater Utilities and PPPs

In the USA, best management practices (BMPs) are generally adopted under the low impact development (LID) approach and diffuse pollution from urban stormwater is a permanent source of concern as it threatens the quality of receiving bodies [17].

Federal regulations for municipal separated systems (MS4s) have been in place since 1990 as part of the National Pollutant Discharge Elimination System (NPDES) to reduce sediment and pollutant loads from urban areas, but in Phase II, which covers municipalities with smaller populations (<100,000 inhabitants), drainage plans are ineffective and stakeholders have little involvement [18].

The main challenge is the control of diffuse sources of pollution using the local authority which has very little control over private properties that are responsible for a large proportion of the sources of stormwater runoff. In addition, the management task is made more complex by limited financial resources and the lack of recognition by the community that drainage and stormwater management are public services and should be understood as such, similarly to water supply and waste collection, and therefore should have sources of funding such as taxes and tariffs that are accepted by all.

The lack of resources means that two alternatives are sought, the first through new taxes. The and lack subsidies of resources and the means second that through two alternatives the creation are of sought, stormwater the first utilities through that new can taxes charge and fee subsidies for services and the use second market through mechanisms the creation(e.g., of discounts stormwater on tariffs utilities for that infiltration can-charge into fees lots for services certain and volumes) market that encourage mechanisms property (e.g., discounts owner on to adopt tariffs stormwater for infiltration management into lots for practices, volumes) if these that do encourage to adopt stormwater management practices, even if these do not always abate pollution.

In Washington, D.C., a market has been created for stormwater credits that are generated concerning the reduction in stormwater runoff on properties. These credits can be traded in an open market where buyers need to meet regulatory requirements or, alternatively, they can be purchased by the Department of Energy and Environment, guaranteeing owners a return on their investment and providing private investment in certain areas of interest to society. At the same time, this stimulates the search for locations to install infrastructure with lower costs.

In a report concerning the responses of the participants of a stormwater utility sur-vey [19] about public–private partnership (PPP) models, 50% of the responses indicated that the use of PPP arrangements was dedicated exclusively to the design, construction, and rehabilitation of traditional infrastructures under new concepts of BMP.

The main management activities included in the annual budgets are related to operation and maintenance, and all issues show percentages of stormwater utility responses above 82%, except for the maintenance of combined systems (66%) and street sweeping (66%). The low number of responses in these two issues, however, is due to the fact that there are no combined systems in most of the participating municipalities and that street sweeping is usually linked to other municipal departments, although it is understood that there is a connection between sweeping and drainage. One aspect to be highlighted is the inclusion of public education as the second most mentioned issue (92%) in the responses.

3.2. China—Sponge Cities Initiative (SCI) and PPPs

China is the country with more experience in PPP arrangements [20], having grown greatly since 2014 with the development of infrastructure projects promoted by the central government. By 2019, 8031 PPP projects were assessed as viable by the Ministry of Finance, with approximate investments of about USD 1.8 trillion in January 2020, but there is no specific law regulating and supervising projects regarding PPP options [21]. The Ministry of Housing and Urban–Rural Development did, however, produce a manual in 2014 that follows LID principles called the "Technical Guidance on Sponge City Construction" [22].

With the growing concern over the flooding caused by rainfall events occurring in several major cities such as Shanghai, Wuhan (2016), Shenzhen, and the capital Beijing itself (2012), the Chinese government has adopted a series of policies and programs regarding drainage systems in cities, the most significant being the national initiative called Sponge Cities (SCI) that was announced in 2014. This is a flood management strategy focusing on the environment and ecosystems with the purpose rearranging the ongoing urban development process, taking into account the urban water cycle [23]. Figure 3 presents the distribution of fifteen of the thirty cities chosen as pilots for the SCI and indicates the average annual precipitation (mm) [24]. The initial budget estimated about USD 1 billion for each one, plus investments from local governments and the private sector.

China, similarly to any country with large territorial areas, such as Brazil, the USA, Russia, Canada, India, and Australia, has a wide variety of geographic and climatic settings. Thus, considering cities with complex climates such as Beijing, located in the north of China in a semi-arid and semi-humid region where there are problems of both water excess and the scarcity of water, sponge infrastructures should take care of storing rainwater to reuse it in times of drought. In the city of Wuhan, for example, located in southern China, the rainfall is greater than 1000 mm and soils are often in a saturated condition, requiring the interconnection of traditional systems (modernizing them) with sponge systems. This demonstrates the need for distinct, specific solutions in each city. About 45% of the cities suffer from insufficient water supply and 17% from total lack of water, and of the 32 metropolitan regions with more than one million inhabitants, 30 face difficulties in meeting their demands [23].

This great existing diversity, however, can be taken as an advantage as long as there is an exchange of experiences among the pilot cities, not only from China, but also from of other countries where the solutions may be applied, but this requires costly learning methods to be stored and constantly updated.

Regarding the attractiveness of private financial resources, the development of business models depends on information and estimates of costs and benefits of sponge city projects compared with the costs of traditional systems, which in China have accumulated rich experience due to the recent exponential growth of the country, including the application of modern technologies. This know-how is a factor that weights in favor of traditional systems, considering that sponge cities, in contrast, are recent and still bring transaction costs such as integration between sectors, scope and learning, and execution time.

Many of the advantages of adopting the SCI are due to economic efficiency gains from benefits arising not only from economic gains, but from the interconnection of investment agendas with other sectors. All these factors are aspects that should be taken into account when designing a business model that can be attractive to private initiatives [23].

The forecast of the subsidies made by the Chinese government's Ministry of Finance for the 30 pilot cities is USD 60 to USD 90 million per year for each city during the first three years. The first group of 16 pilot cities is expected to receive investments of USD 13 billion during the first three years for an estimated total construction of 450 km2, which translates to USD 29 million per km2. According to the National Development and Reform Commission (NDRC), to achieve the planned amounts, the government encourages private participation through innovative arrangements such as PPP arrangements [23].

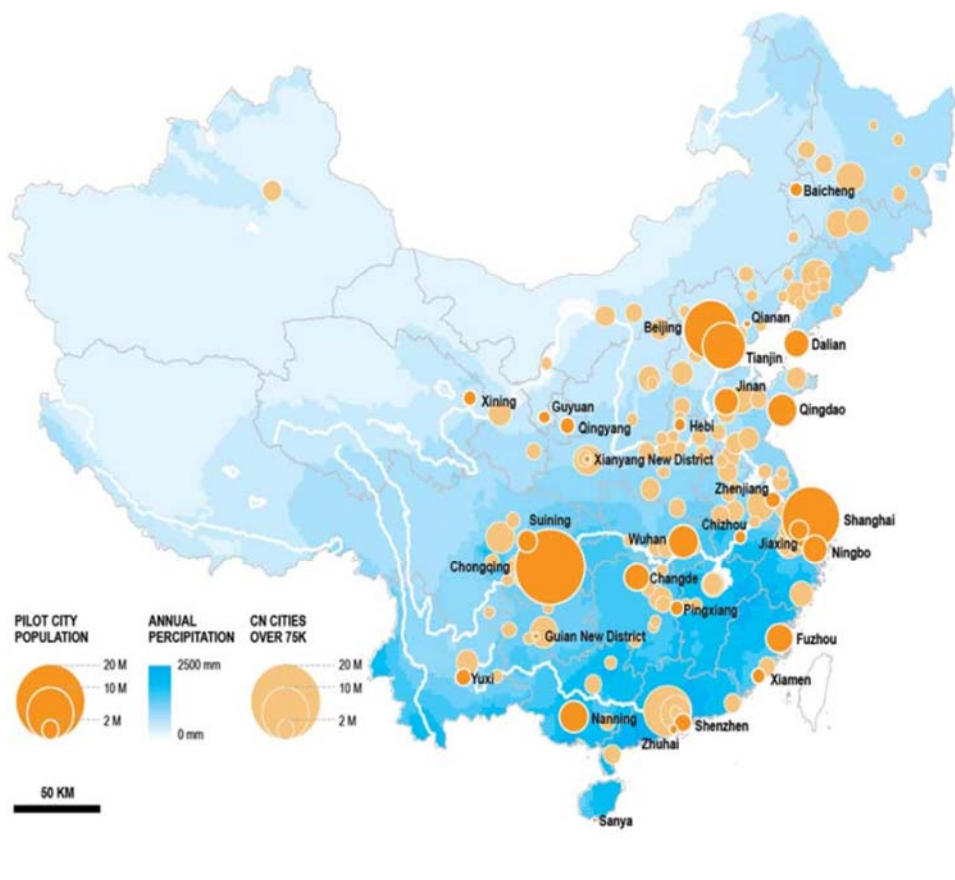


Figure 3 - Spatial distribution of the cities selected for the Sponge Cities pilot project with average annual rainfall [24]. Reproduced with permission from author.

Regarding society's perceptions and knowledge about SCI, such as its willingness to support the initiative through the payment of additional amounts in water tariffs or the purchase of government-issued bonds (3.9% return annual rate), a public opinion survey was conducted in 2016 in the cities of Zibo (4.61 Mhab) and Dongyingn (2.09 Mhab) in Shandong province, one of the most important and industrialized provinces in China (third in terms of GDP and second in population) that is subject to rapid urbanization and has frequent problems with water supply and urban flooding [22].

The results showed knowledge of the SCI and its objectives and the perception that subsidies and PPP arrangements are the main forms of financing the initiative; furthermore, respondents accepted the idea of a 17% increase in water prices to finance the construction of sponge cities. However, concerning investments, responses showed a willingness to spend, with the acquisition of SCI-related bonds, on average up to 55% of their annual surplus income. China, therefore, emerges with a bold current vision for private investment and participation in the stormwater sector.

3.3. Portugal—A Hybrid Model on the Right Track

In Portugal, the responsibility for stormwater management lies with the municipalities, which can delegate their operation to management entities through a specific contract. However, as there are two types of infrastructure systems—separate and combined—the former can be managed by two different entities, i.e., one for wastewater and the other for stormwater, although this may mean a loss of scale compared to the joint management that occurs in most systems, which are combined.

Decree-Law no. 194/2009 allows for joint management, although it does not clarify the form of cost recovery, and tariffs are subject to the approval of the Water and Waste Services Regulatory Authority (ERSAR).

In the discussion of the Strategic Plan for the Water Supply and Wastewater and Stormwater Management Sector 2030 (PENSAARP 2030), it was considered to make stormwater management a responsibility of the wastewater services —and thereby re-moving it from the duties and responsibilities of the municipalities. Currently, the services are provided by the municipalities themselves, by municipal companies, or by concessionaires, and may be attached to urban cleaning services.

However, whatever the form of management, one issue is the determination of the upstream and downstream boundaries of stormwater systems, with various types of consequences, such as the maintenance of urban cleaning (the cleaning of gutters, drains, watercourses, and beaches).

Currently, even though municipal water companies have legal status under private law, what is also being discussed is the feasibility of giving water customers a fourth service on their bill related to rainwater, in addition to water supply, wastewater, and solid waste, and the repercussion on the capacity of customers' budgets and the budgetary burden for water services [25].

The issue of resources to be invested—as demonstrated by the investment budget of the Lisbon General Drainage Plan (PGDL) 2016–2030 which, for fifteen years, reached the figure of EUR 250 million (only the cadastral survey, completed in 2020, had a budget of EUR 1.7 million)—raises the question of what is the best way to provide resources to finance actions.

Thus, PSP in stormwater drainage and management services in Portugal still has a long way to go and will require the definition of several issues, including the participation and sharing of obligations in society, some of which have been raised in this text.

3.4. Argentina—The Privatization Experience

The private concession of the WSS carried out in the metropolitan region of Buenos Aires presents aspects related to integrated water management that explicitly demonstrate the interrelationship between surface water (including stormwater) and groundwater. The region is located on the banks of the Rio de la Plata, a practically inexhaustible source of surface water, and at the same time is located up a system of underground aquifers of which the hydraulically connected Pampeano and Puelches aquifers are part [26]. These groundwater aquifers are water tables from a few centimeters to 5 m below ground level and extend up to 60–70 m in depth, suffering from overexploitation [27].

Despite the existence of aquifers with good quality water, the concession only provided for the use of surface water, also of good quality, disregarding the possibility that the poorest areas could be supplied by groundwater through the drilling of wells. Although it was accepted that this could happen, the concessionaire of Aguas Argentinas SA (ASSA) from the Suez Group did not carry out work in areas that did not have access to surface water.

The initial proposal provided for the service of the entire population without any conditions—that is, the universalization of the WSS regardless of the purchasing power, ownership, and infrastructure of housing—until the end of the term of the concession contract (thirty years).

It should be noted here that issues of ownership, housing infrastructure, and the provision of public services—which in the period before the concession were dealt with only between the municipality and the residents—now have a new entity: the private company. The recognition of property rights and the right to access the WSS are two interconnected processes, and privatization carries conflicting aspects such as, for example, the resistance to paying concessionaires for connections to the network—which are up to USD 400 to 600 for water and USD 1000 for sewage [28]—by customers who do not own legal lots and are unsure of their permanence in the place. This is a matter handled by the government.

Universalization through the privatization of services encounters difficulties related to the urban planning processes of cities, especially in their poorest neighborhoods, which are exactly where the greatest deficits in the provision of the WSS are found. The greatest deficits in land regularization and the infrastructures of stormwater drainage are important parts of the system.

In the specific case of Buenos Aires, 25% of areas covered by the concession comprise a poor population (2 million people), making these issues very important.

From the late 1990s onwards, another relevant aspect regarding drainage, especially in the case of the metropolitan region of Buenos Aires, was the rise in the water table due to the closure of underground extraction wells due to the decrease in industrial activity, and also the contractual policy of using a single source of supply for surface water, plus the option of expanding networks with a relatively small increase in the sewage system and a great increase in the supply network [28].

The rise in the low level of the water table caused a decrease in the infiltration capacity of the land and an increase in the number of supply networks without the counterpart of sewage, which caused less water to flow out than enter the region. Thus, especially in moments of high water levels in Rio de la Plata, urban flooding occurs. The population’s perception of the connection between these flood events and the “single source” contractual policy with little drainage has created consequent dissatisfaction. This is a factor considered as one of the causes for the failure of the concession contract to the private sector.

The first water services concession contract was signed in 1993, immediately before the 1994 constitutional reform, and the Suez Group announced its intention to disengage from participation in Aguas Argentinas S.A. in September 2005.

The lessons taken from the Buenos Aires experience reveal that not considering all aspects involved in urban water issues, in particular stormwater management, can jeopardize the feasibility of universalizing the WSS.

3.5. Germany—Participation of Landowners in Berlin

In new neighborhoods and subdivisions, it is possible to implement decentralized urban drainage management by installing devices on lots, and municipalities can make their own choices for decentralized drainage policies. However, in older neighborhoods with traditional (centralized) urban infrastructure already in place, carrying out required incentives depends on instruments that are generally supported by legislation and local rules, leading owners to adopt them.

Research conducted in Germany in 44 municipalities addressed the incentives for owners to adhere to decentralized management and, from the point of view of the New Institutional Economics theory, two institutional aspects of the municipal management of urban drainage present in all municipalities were analyzed: the first was the compulsory connection and use of existing networks, and the second was the taxes (from EUR 0.29/m2 to EUR 1.93/m2 with the unweighted average of the sample equal to EUR 0.85/m2) and discounts applied. The analysis took into account the interaction between institutions (interplay) and contradictions with the refinancing of the existing infrastructure, as well as the risk of the loss of controllability due to the large number of people involved in management [29].

In Germany, various mechanisms can be used to encourage the adoption of decentralization measures, and among these various other institutional aspects of municipal urban drainage management, such as land use planning, the mandatory use of green roofs, local funding programs, information campaigns, and restrictions on the use of centralized systems have been implemented.

Ideally, the design of the institutions should be conducive to the achievement of the objectives, i.e., to urge private owners to participate in urban drainage management, thus contributing to the municipality achieving its objectives, including better urban flood control and lower drainage infrastructure costs.

Figure 4 shows two previous planning stages, the objectives and integration strategies of the owners before the design of the institutions, and the two institutions under study, with the first being the compulsory connection and use of the networks, and the second the taxation of drainage systems. Furthermore, the interaction between the two institutions (the institutional interplay), the conditions for their adoption and operation, and the owners' investment decisions harmonized with the objectives and strategies previously planned are presented.

Two decentralization strategies (integration of landowners into stormwater management) can be implemented; landowners are more likely to adhere to decentralization with higher fees and discounts. There are two other strategies that are considered to exclude landowners in management. Thus, there are four different institutional conceptions: forced decentralization and selective decentralization (more inclusive of private participation by property owners in management) or, alternatively, an extension of the public network and maintenance of the status quo (more exclusive of private participation).

In the first case, for forced decentralization, there is no compulsory connection, the fees are high, and many discounts are offered. The option is favorable to municipalities that are highly dependent on the contribution of property owners for the protection of surface water for water balance and flood protection, and where a high potential for conflict over refinancing and a significant loss of control are accepted.

In the second case—selective decentralization—there is no compulsory connection, high fees, and no rebates. This concept promotes the protection of surface water against flooding with the water balance receiving support from landowners, and may be the option for municipalities that accept high risks related to refinancing and loss of controllability.

The third case – guaranteeing the extension of the public network – combines compulsory connection with high fees and no rebates, and can be chosen when it is desired that the owners contribute by co-financing the public system while maintaining a low refinancing risk and no loss of controllability.

The fourth option – status quo – is a combination of compulsory connection, a low level of taxation, no special rebates, minimizing incentives for owners to decentralize, creating long-term controllability, and ensuring no refinancing conflict. This is a good choice for municipalities where small charges can be supported to achieve the objectives of stormwater management.

Taxes are usually used to finance existing systems under the vision of cost recovery, which can lead to high taxes according to the needs of these systems. Thus, policies of incentives to decentralise through discounts can lead to a certain number of disconnections from the network with a loss of revenue, but also a decrease in demand. On the other hand, the lower the charges and the lower the incentives for disconnection, the greater the possibility of maintaining the status quo, that is, of the systems requiring ever greater resources.

Using a geographical information system (GIS), it was found that even in densely populated areas of Berlin, it was easily possible to disconnect 30% of the impervious areas in 22 km² catchment area with a separate sewage system [30].

Taxes have an ambiguous role as both a source of revenue for the refinancing of existing systems and a source of incentive for the decentralization of the systems, which also makes them a source of revenue loss due to possible disconnection.

From an economic point of view, there are arguments against decentralization, such as the devaluation of investments already made and the risk of growth in costs and charges, combined with the loss of economies of scale and high transaction costs [29].

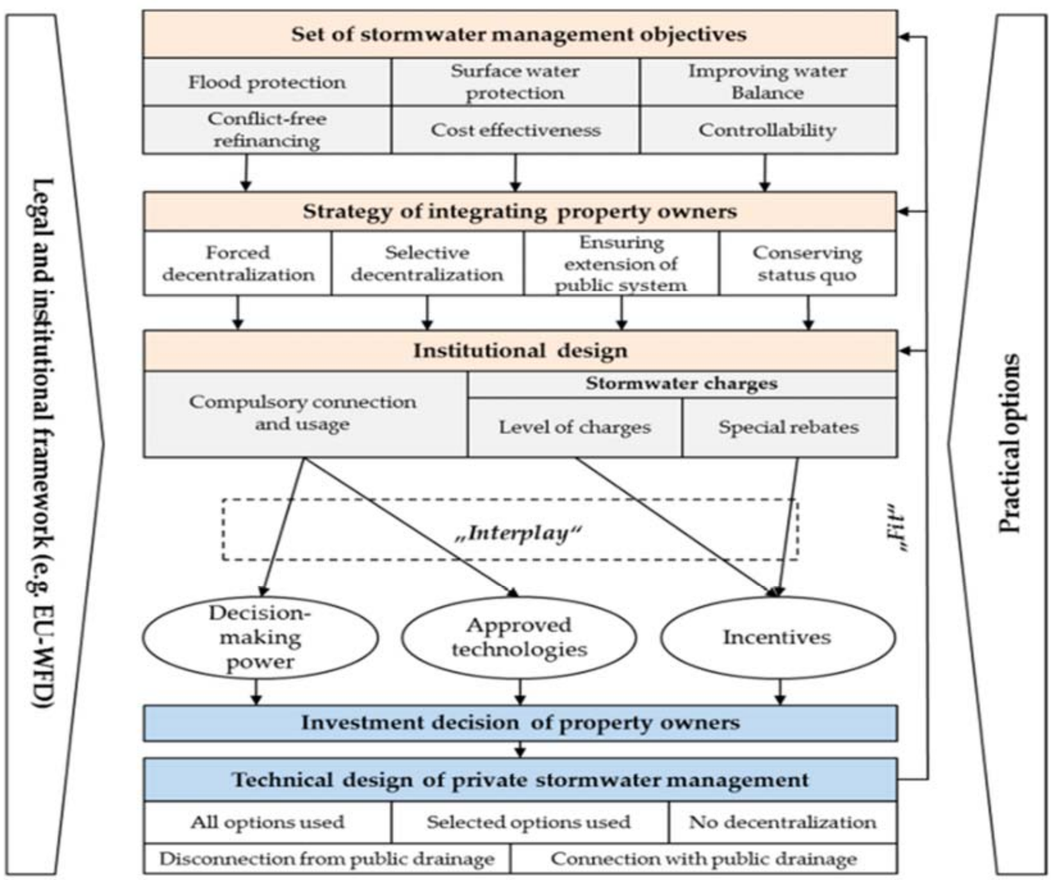


Figure 4 - Conception of institutional design: external influences and effects on private stormwater management [29]. Reproduced with permission from Stefan Geyler, Sustainability; published by MDPI, 2019.

Despite its advantages, the issue brings complexity by requiring the determination of the balance between the values of charges, the needs of existing systems, discounts for disconnections as incentives for owners, and the risk of loss of control over the management of the systems due to the greater number of participants.

### 3.6. Australia—Water Markets

In Australia, the water-sensitive urban design (WSUD) concept is widespread and separative systems have been implemented, but there is still a need to expand the knowledge of stormwater resource use within the urban water cycle, creating the possibility for more effective economic and business plans. Concerning private participation through charging, the example of Melbourne can be cited, which in 2016 received AUD 6645/Kg per year for stormwater nitrogen loading [31].

In Melbourne, economic aspects had a strong influence on the private solutions adopted, such as PPP arrangements for large projects. They also acted as an incentive to build an additional private network for a recycled wastewater supply. The existence of funding for the installation of rainwater tanks as an alternative source of non-potable water was also used as an incentive for the adoption of the solution [32].

The creation of a market for the transaction of water access and use rights, called the Water Market, was conceived in Australia as a way to address, especially in times of scarcity, a better balance of use in rural areas. However, despite the political and institutional constraints to its use in transactions between rural and urban areas, Adelaide, Bendigo, and Ballarat have used this mechanism to circumvent urban scarcity problems [33].

## 4. Brazil

Brazil has a long history of reactive actions to public service delivery issues with very little planning. Here, we focus on the specific aspects. Several issues contribute to this, such as the frequent change in political direction after elections; the reduced knowledge and participation of the population; the lack of institutionalization and organization of specific administrative structures; regulations being in infancy; corruption, diversion, and the poor allocation of resources; lack of prioritization; lack of political will; and the poor teaching of current drainage techniques, among many others, that may occur simultaneously or not [11]. Despite this terrible picture, several initiatives continue to be tried and deserve attention, and we will look at them to try to extract good examples for the evolution of the stormwater management debate.

### 4.1. São Paulo

In Brazil, there is a multiplicity of actions regarding urban stormwater drainage and management, especially in large municipalities, the most populous among them being the city of São Paulo. This metropolis opted, like 665 other municipalities, according to the Basic Sanitation National Plan (PNSB) of 2008 [34], for the construction of several temporary rainwater detention reservoirs as a way to attenuate the precipitation peaks and volumes in the municipal region.

In this municipality, PSP was considered in one of the last actions of 2020 through an arrangement in the modality of administrative concession, i.e., the main payments to the concessionaire would be made directly by the municipality, additionally allowing the latter to obtain ancillary revenues. In this specific case, such revenues would come from the commercial exploitation of air spaces located above four existing stormwater detention and retention reservoirs (Sharp, Guaraú, Anhanguera, and Rincão). The main objective of the contract was the requalification, operation, maintenance, and conservation of the four existing reservoirs, as well as drainage interventions for the five micro basins of the municipality. The total expected value is USD 257 million over the 33-year term of the contract [35].

Only by way of comparison, according to the recent Basic Sanitation National Plan (PLANSAB) of 2013, the estimates of resources to be spent on urban drainage in Brazil by region are presented in Table 1.

Table 1 - Investments in urban drainage by 2033 [34].

Investments (Millions of USD)

| | **Expansion** | | | **Replacement** | | | **Total** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Region** | **2014-2018** | **2018-2023** | **2023-2033** | **2014–2018** | **2018–2023** | **2023–2033** | **2014–2018** | **2018–2023** | **2023–2033** |
| North | 932 | 1.045 | 1.665 | 106 | 203 | 427 | 642 | 1.248 | 2.093 |
| Northeast | 3.074 | 3.465 | 5.453 | 304 | 585 | 1.255 | 2.072 | 4.050 | 6.677 |
| Southeast | 3.529 | 3.956 | 6.140 | 1.100 | 2.166 | 4.359 | 3.129 | 6122 | 10.499 |
| South | 8.466 | 9.696 | 14.618 | 551 | 1.089 | 2.185 | 5.420 | 10.785 | 16.803 |
| Center west | 1.262 | 1.435 | 2.179 | 317 | 629 | 1.258 | 1.043 | 2.064 | 3.438 |
| Total | 17.263 | 19.597 | 30.055 | 2.378 | 4.672 | 9.454 | 12.306 | 24.269 | 39.509 |

### 4.2. Brasília—Federal District

In Brasilia, the federal capital of Brazil, located in the Federal District (DF), the responsibility for the provision of urban stormwater drainage and management services lies with the Companhia Urbanizadora da Nova Capital do Brasil (NOVACAP), according to District Law no. 4.285/2008 (arts. 51 and 52). Article 51 states that NOVACAP will be granted a concession contract with the Federal District's Water, Power and Sanitation Regulatory Agency (ADASA) for thirty years, renewable for up to twenty years at the discretion of the executive power, and that a PPP contract will be signed to make the services economically viable.

When the legislator present in the law affirms the intention of seeking the economic viability of services through the forecast of PPP arrangements (Article 51), and charging (Article 53) indicates the intention of PSP, that has, as will be seen further on, not prospered (at least up to now), this characterizes a case of mimetic isomorphism—in other words, the copy of an existing model in operation in other contexts, but without its effective placement in practice. It is thus a contradictory situation between “de jure” and “de facto”, as pointed out by some authors [36].

NOVACAP, a public company, however, is not a specialized body for this activity and disputes tax revenues for many other purposes. Furthermore, the concession contract envisaged in Article 51 of the law, according to part of the doctrine, brings contradictions since the NOVACAP company cannot be treated as a concessionaire since it is a political entity holding a public service, and perhaps this is why such a contract was not signed [37].

Besides NOVACAP, the Department of Highways (DER) is also in charge of urban drainage, since several highways cross the urban areas of the Federal District requiring the management of the interface between these agencies.

The economic and financial sustainability of these services, according to the same law (District Law no. 4.285/2008, Article 43) provides collection in the form of taxes, following the regime of the provision of services and their activities. However, more than ten years later this has not yet been implemented, making it difficult to face the issues posed by the Urban Drainage Master Plan (PDDU) and confirmed by the District Plan of Basic Sanitation (PDSB) of the Federal District (DF 2017).

Article 53 of the same law (District Law no. 4.285/2008) provides charged public services for the drainage and management of urban rainwater taking into account, in each lot, the percentages of impermeable areas and the existence of rainwater damping and retention devices, in addition to other criteria such as income level of the population of the served area, the characteristics of the urban lots, the areas that can be built on them, and the effective drainage area in the case of completed construction, evaluated according to technical criteria established by ADASA. However, the executive power has not yet taken any initiative to implement the charge.

Despite the absence of a specialized body to provide services and a specific source of resources for the financial support of the activity, ADASA has been carrying out several important actions to organize the sector.

Such actions include the elaboration of a drainage and stormwater management manual and the monitoring of the elaboration of the PDSB that identified the need for institutional development and infrastructure deficits. A review of the DF drainage system cadaster was also made, in addition to GIS development, the proposition of control of sediment generation by civil construction works incorporated in the new DF Works and the Buildings Code, and guidelines for public works.

Another work performed by ADASA was the assessment of the extent and composition of the DF’s public and private sealed areas through high-resolution images, as summarized in Table 2. Finally, the identification of options for the institutionalization of service provision, including the feasibility and legality of charging, modelling the charging structure involving sealed areas, social tariffs, cross-subsidies, and other parameters for the assessment of annualized reference costs to be covered, was completed [37].

Table 2 shows that private impervious areas are approximately equivalent to public areas, suggesting the possibility of the joint participation of the public and private sectors in the revenues to support the economic and financial management of stormwater drainage and management services in the Federal District.

Table 2 - Typology and extension of impermeable urban areas in the Federal District (adapted from [37]).

| Typology of Impermeable Urban Areas | Área ($m^2$) | Percentual (%) |
|---|---|---|
| Public Common Use Impermeable Area | 213.864.804 | 44% |
| Private Impermeable Area (plots and projections) | 201.566.138 | 42% |
| Shaded Areas | 68.284.851 | 14% |
| Waterproofed area analyzed | 483.715.793 | 100% |

5. Results and Discussion

The objective of attracting private capital requires solid strategies based on a vision of consolidated social interests and priorities clearly expressed not only in general public policies that have attractiveness as one of their objectives, but also in specific public policies that, for example, determine the priority areas of action, as seen in China, where pilot projects were concentrated in 30 cities. It was, however, the problem of floods and water scarcity that pushed action in the direction of Chinese sponge cities [38]. Table 3 shows the main pros/cons and barriers.

From climatological and hydrological mapping combined with historical occurrences and the existing infrastructure in each place, one can have a starting point for determining these priorities. This alone, however, is not enough, as there remains the issue of quantifying the resources needed for the actions. This quantification requires knowledge of the cadasters and the updated situation of the infrastructure, in addition the dimensions of events with several return times and the respective associated costs. The determination of the technical structures (human and material resources) on which the responsibility and deadlines should fall to accomplish the tasks mentioned above passes through the existence (or construction) of these structures, and also the “rules of the game”, for this to happen.

In large countries such as Brazil, China, and India, prioritization is part of the game, despite the importance of building national guidelines. However, prioritization requires knowledge of the problem and strategies for action, i.e., data, information, and planning, without which there is no business management towards solutions

Table 3 - Main pros/cons and barriers to implementing PSP.

| Pros | Cons/Barriers |
| --- | --- |
| Other sources of funding | Corruption and inept governments |
| Sharing risks between public and private sectors | Transaction costs |
| Internalization of externalities | Institutional and environmental contexts |
| Greater efficiency in management | Difficulty in measuring before and after |
| Possibility of using project finance | Absence of policies aimed at PSP |
| Possibility of regulation | Lack of regulation and inexperienced staff |

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However, with a passive policy in the face of reality, in the simple expectation that municipalities can formulate their demands for the supply of resources from the central government, as it has been happening in Brazil, an undesirable selectivity of municipalities occurs without achieving the objectives for the application of available resources, nor the control and solution of the problems of flooding in the places where they are most critical. The choice for the allocation of resources based only on the existence of projects that comply with legal accounting rules results in actions centered on municipalities that do not necessarily keep close correlation with the priorities and problems focused on by pro-active policies, which aim to solve them and present results in well-defined time horizons.

The attractiveness of private capital must overcome this bureaucratic–technical frontier for the allocation of public resources and focus on the solution of problems without the restrictions required by the resources of public budgets, that is, the solutions must be the responsibility of the private capital, especially for its economic sustainability, making use of accounting by showing the expenses and revenues of the projects from a perspective more linked to project finance than to subsidies and governmental contributions, even if this requires extending the life of the projects.

In Brazil, the scarcity of resources in public budgets finally led to escape from the trap of the controversial debate between forms of capital (public or private) to be applied in solving problems related to the WSS, especially the issue of universalization. By opting for private capital and an increase in PSP, the need for its regulation was verified and thus depends now on the elaboration of rules for regulation through a specific agency [39]. However, as a centralized decision solution, defined from top to bottom without any participation of society, there is the risk of practicing a kind of mimetic isomorphism and at the same time forgetting the complexity of the sector, especially the local aspects, which are particularly expressive concerning stormwater management, and reaching questionable results.

Drainage pricing in almost all charging initiatives is vital to sustaining programs, as is the case in the USA, which has proven sensitive to public understanding and support than when it comes to water supply and wastewater runoff. In Brazil, this should be similar and they should encounter barriers with the adoption of top-down solutions. Of all the sub-national regulatory agencies, only one (ADASA) has tackled the issue of drainage regulation, however, without addressing pricing issues.

Under this view, projects deserve to broaden their objectives and include systems other than just urban drainage and stormwater management. The concessions of areas such as zoos [40], for instance, in which detention or infiltration basins can be included, may allow their financing in part through entrance fees and other revenues linked to the parks.

In the case of mapping, there is ample climatological documentation, which should, however, be permanently updated in light of climate change. In the case of Brazil, the National Sanitation Information System (SNIS) database deserves to be improved to apply the above vision.

In Brazil, the coordination of this information (climate, infrastructure, and feasible concessions) requires the participation of staff structures that include people and resources to format projects which, if successful, can serve as an example so that other cases can be executed. This takes time, and the implementation of this vision must urgently start so that know-how and private capital participation can contribute to urban stormwater management as soon as possible. In China, it is estimated that the experience should take a generation [41].

## 6. Conclusions

Concerning PSP in urban drainage systems, there is a long way to go given the current situation, both in terms of independent organizational structures, cost segregation, and investments to be made. All, in turn, depend on political options, institutions, and management techniques such as, for example, the different policies of forms of use, e.g., resources, non-potable or potable, treatments, and decentralization, each with different applicable technologies (infiltration, aquifer recharge, green roofs, cisterns, disconnections, and impervious area removals). Through case studies in different countries, an overview of PSP in the drainage and stormwater system sector has been presented, seeking to present the reasons that underpin the importance of PSP, as well as the pros/cons and barriers to its implementation.

This study aimed to verify—based on the idea that PSP can bring important contributions to the public services sector with the main driving forces of attractiveness to capital and efficiency—how PSP has worked in practice, using urban stormwater management services as an object of study. A critical analysis of the relevant aspects found in several existing cases in four continents, but with a special focus on Brazil, was synthetically carried out, and characteristic aspects with the potential to be useful to reflection due to their singularities or similarities were presented.

The subject was approached in several ways, but brings greater focus on the economic aspects involved, which is a point of great relevance given the rise in the scarcity of public budgets, aging infrastructures, and climate and demographic change demands. The lack of a wider approach to the advantages and disadvantages involved in the other aspects can be considered one of the limitations of the work.

Finally, what is certain is the fact that within the urban water cycle, rainwater is becoming increasingly more important. Calling attention to its use leads us to demand the study not only of ways to use it, but also of the institutions and organizational structures involved in its management, as the existing and traditional ones are not adequate or attractive to private sectors. Thus, by utilizing this resource appropriately, the challenges of stormwater PSP will become just another summer dream.

Author Contributions: Conceptualization, C.N. and R.M.; methodology, C.N. and R.M.; validation, C.N. and R.M.; formal analysis, C.N. and R.M.; investigation, C.N.; resources, C.N. and R.M.; data curation, C.N.; writing—original draft preparation, C.N. and R.M.; writing—review and editing, C.N. and R.M.; visualization, C.N. and R.M.; supervision, R.M.; project administration, R.M.; funding acquisition, C.N. and R.M. All authors have read and agreed to the published version of the manuscript.

Funding: The authors are grateful for the Foundation for Science and Technology's support through funding UIDB/04625/2020 from the research unit CERIS.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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