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An overview of urban drainage systems and their management in Brazil

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ABSTRACT

Urbanization is closely linked to the history of humanity, from nomadic peoples to the present day. Water has always played a crucial role in the founding and development of cities, influencing not only survival and agriculture, but also sanitation. The Roman Empire was a milestone in the development of urban sanitation, with the implementation of sewage systems and public toilets. However, despite advances throughout history, many areas still face challenges in accessing basic sanitation, including Brazil, where poor infrastructure is a problem, especially in the North and Northeast regions. Brazilian legislation has established guidelines for the management of urban stormwater, but the misuse of drainage systems remains a problem, resulting in pollution and public health risks.

Keywords: Urbanization, Water, Sanitation, Brazil, Drainage.

INTRODUCTION

The foundation of the first cities can be traced to the sedentarization of nomadic peoples, who sought places close to water sources to guarantee the supply and develop agricultural and livestock activities. The importance of water has transcended simple consumption, influencing urban planning and development since primitive times. This resource was essential not only for survival and agriculture, but also began to play a crucial role in sanitation, being used for the transportation of human and animal waste, which initially contributed to the spread of diseases due to improper disposal on public roads.

During the Roman Empire, there were significant advances in sanitation infrastructure with the construction of public toilets and latrines and the implementation of the Roman Cloaca Maxima, a sewer system to drain stormwater and sewers. These innovations represented a milestone in the development of basic sanitation, with the aim of improving sanitary conditions and reducing the health risks associated with the presence of waste and rainwater accumulation. This period is highlighted as one of the first examples of a conscious effort to deal with the challenges of sanitation in urban areas (Caminha, 2014).

However, with the passing of the centuries and the accelerated urban development, especially motivated by the rural exodus, basic sanitation services have not been able to keep up with the pace of

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population growth. Globally, millions of people still live without adequate access to these essential services, facing significant risks of contamination from waterborne diseases. In Brazil, the situation is similar, with ongoing efforts to universalize access to basic sanitation, although many areas, especially in the North and Northeast regions, remain vulnerable due to poor infrastructure (UN, 2014).

Brazil's Law 11.445/2007 established important guidelines for the management and management of urban rainwater, underlining the need for drainage systems that protect life, property, and public health. Despite these advances, reality still shows that many drainage systems are inadequately utilized for the transportation of untreated sewage, resulting in significant pollution and health risks. This highlights the urgency of monitoring and improving urban drainage systems to address environmental and public health challenges, thereby ensuring a better quality of life for urban populations.

OBJECTIVES

Show the context of urban drainage in the country, showing the advances found in the knowledge of the problem and the challenges to move forward;

Present, mainly, the management of the urban drainage system;

To conduct an exploratory research analyzing academic articles on the main means of urban policy and management in urban drainage systems.

METHODOLOGY

To begin the discussion of this work and a broader view of the data available in the literature about urban drainage systems and their management in Brazil, the literature review strategy was used, bringing evidence of the importance and applicability of the proposed theme, in addition to corroborating the safety of the study through a research process.

A review aims to minimize errors, collecting reliable studies on the subject with pertinent conclusions and supporting the justifications of decisions by the author of the present study.

In this context, some essential steps are necessary for a satisfactory literature review, such as the definition of clear objectives, the establishment of criteria to elect the most appropriate articles for the study, the adjustment of a methodology, an effective search that can collect the eligible articles, and the presentation of the information of interest in a summarized form through comparative discussion of the results.

To trigger the conduction of the literature review, strategies were defined through the development of the methods of synthesis of the articles used. In order to highlight the process by which this review was conducted, Table 1 presents the phases covered in this method, accompanied by their characteristics and main steps.

The first step was the definition of the motivating question, which is justified by the need to offer a satisfactory contribution to the state of the art of urban drainage management in parallel with the defined objectives of the work.

The designation of the motivating question aims to narrow the field of action of this study and limit the research, directing it to studies that will really be useful in the discussion and comparison of results. The motivating question defined was: How does the management of urban drainage systems in Brazil behave?

Table 1 - Stages of Literature Review

Steps	Description
Definition of the motivating question	How does the management of urban drainage systems behave in Brazil?
Choice of keywords	Management, Stormwater, Urban drainage
Search strategies	Search by title, abstract, and keywords
Collecting jobs in the database	Reading of titles and abstracts with collection of relevant studies and exclusion of non-relevant works
Information extraction	Reading, classifying and organizing information
Analysis of the results	Evaluation and discussion on the motivating question
Summary of the review	Summary of results and writing of the review

Therefore, the terms were entered in the search field and the demand in the title, abstract and keywords was selected in the database for the retrieval of studies that are of interest and will add to the search. It is important to justify that there was no prioritization in the use of the criterion of studies published only in the last 5 years, since it would further limit the search for articles on the theme, since it is a topic that has been evolving since the creation of cities, as previously highlighted.

DEVELOPMENT

RAINWATER DRAINAGE IN BRAZIL

In Brazil, urban drainage systems have always been in search of the most effective hydraulic system. Focused on a hygienist view, the notion of sanitation (in the sense of making the environment healthy) represents the need to "always drain", creating micro and macro drainage structures to conduct water out of cities (Souza, 2013).

This approach results in the very concept of urban drainage system adopted in Brazil, present in most urban drainage manuals: a set of elements intended to collect rainwater precipitated over a given region and that runs over its surface, leading it to a final destination. As Botelho (1998) points out, rainwater drainage systems should be dimensioned based on collecting rainwater and conducting it quickly downstream. In a simplistic view, the problem is only to calculate flows and size the conduits and galleries to transport them.

The result of this approach is a detachment between city planning and the development of drainage systems: with rare exceptions, the city ignored watercourses in the occupation of space, occupying areas of naturally flooded floodplains, and left it to the drainage technique as a result of the recognition that cities are spaces of denial of nature.

Interventions are often justified by arguments that intervention is in the riverbed itself, which is degraded, has no negative impact, but positive (Vieira; Brito, 2008). It should be noted that the promises in channeling works are always to solve flooding problems. In this situation, it is a process of dehumanization of the water body, in a clear relationship of utilitarianism of urban channels, natural or artificial, with the sole function of draining, with no relationship with society or other environmental functions, with the ecosystem.

More recently, the perception of the limits of the traditional approach has led to some important changes regarding the adoption of non-structural measures and, in this sense, Belo Horizonte has been one of the pioneering cities in a new treatment of urban drainage. In addition to the structural measures, an alternative for adapting to the problem of flooding has been used from the elaboration of the "Belo Horizonte Flood Map" (Belo Horizonte, 2009), based on hydraulic and hydrological modeling: to inform the population about the possibility of flooding at certain points. This instrument, combined with monitoring and warning systems, allows adaptation to risk – one of the new concepts in the current approach to drainage and which has been incorporated in some cities.

In this new approach, some intervention initiatives deserve to be highlighted, such as the DRENURBS Program (in Belo Horizonte), the Clean Stream Program (in São Paulo) and the Tijuco Preto Stream (in São Carlos). In the latter, the intervention resulted in the revitalization of a stretch of the stream, initially channeled, creating a linear park space, with recomposition of riparian vegetation and creating a space for coexistence with the water. The DRENURBS Program seeks intervention in order to insert an environment of coexistence with the watercourse, through linear parks. Two aspects deserve to be highlighted in DRENURBS: the first is that the main guideline is for minimal intervention in watercourses that have not yet undergone a channeling process; and the second is the participation of the local community in the design of interventions and in the maintenance of the environment.

WATER QUALITY

The study of the quality of urban rainwater drainage involves understanding its complete cycle, starting with precipitation that leads to the leaching of pollutants from the atmosphere and particulate matter, which eventually precipitate along with water vapors (Henriques, 2014). This stage is followed by runoff, whose water quality is directly influenced by the characteristics and activities in the watershed, including land use and the differences between paved and unpaved areas. The nature of the pavement

significantly affects the runoff process, where porous pavements facilitate water percolation and infiltration, while impermeable surfaces, such as asphalt, rapidly increase the volume of runoff, which can overload drainage systems (Henriques, 2014).

Stormwater quality is determined by a variety of factors, including local geography, weather conditions, the presence of vegetation, and pollutants. Generally, the waters transported by urban drainage systems contain a variety of contaminants, such as sediments, nutrients, organic matter, chemical compounds, heavy metals, and microorganisms (Caminha, 2014). Pollutants in drainage systems may originate from point sources, such as inadequate sewage discharges, or from diffuse sources, which are prevalent due to the carry-over of pollutants by surface runoff, especially in urban areas with a high concentration of commercial, industrial, or highway activities, where runoff composition varies significantly (Ahlman, 2006; Xia *et al*., 2020).

The frequency of urban cleaning, precipitation patterns and land use are some of the factors that influence the quality of water drained in urban drainage networks. In the Brazilian context, rainwater is legally classified as sewage, due to the variety of impurities that it carries to water bodies, negatively impacting the use of these resources for human supply (Silva, 2004). However, the quality of rainwater may vary, and initially it may be more contaminated, but subsequent volumes of rainfall may present a quality comparable to that of springs used for consumption, according to World Health Organization criteria.

The monitoring of the quality of urban drainage water is carried out through the analysis of physical-chemical and microbiological indicators, allowing the evaluation of the presence of organic pollution and metals, among other contaminants. This monitoring is essential for the proper management of these waters and for the prevention of negative impacts on the environment and public health (Coelho *et al*., 2012). The problem of contamination of drainage water by sewage is also emphasized, often due to the inadequate use of sewage systems and poor management by local authorities, which reinforces the need for improvements in infrastructure and urban environmental management (Tucci, 2006).

Inadequate drainage water quality not only threatens environmental sustainability, but also impedes efforts to improve the quality of water from natural water sources. The presence of contaminated tributaries in streams and rivers has adverse effects downstream, contributing to problems such as siltation, eutrophication, and the introduction of pathogens and pollutants, highlighting the urgency of integrated and sustainable approaches in urban water management to protect aquatic ecosystems and public health (Gomes *et al*., 2023).

RAINWATER MANAGEMENT

According to Henriques (2014), the pressure caused by the increase in the urban population on the natural environment is highlighted all over the world, providing undesirable aspects on all the characteristics of basic sanitation, especially in the urban drainage of rainwater. Due to the disorganization of growth, populations are increasingly invading areas that are unsuitable for housing and without respect for land occupation, as determined by law from the Municipal Master Plan.

For Silveira *et al*. (2002) it is only likely that urban drainage management can be achieved with an understanding of the concepts in question, especially the difference between microdrainage and macrodrainage systems, both showing many criteria for their implementation (Matos, 2003; Menezes, 2004). In view of this situation, it is possible to define microdrainage as the rainwater conduction or collector system, showing street pavements, curbs and gutters, manholes, network of galleries and small canals in its infrastructure. For macro-drainage, a larger system involves, in addition to the micro-drainage system, works and structures that help protect against erosion and siltation, especially of the receiving bodies.

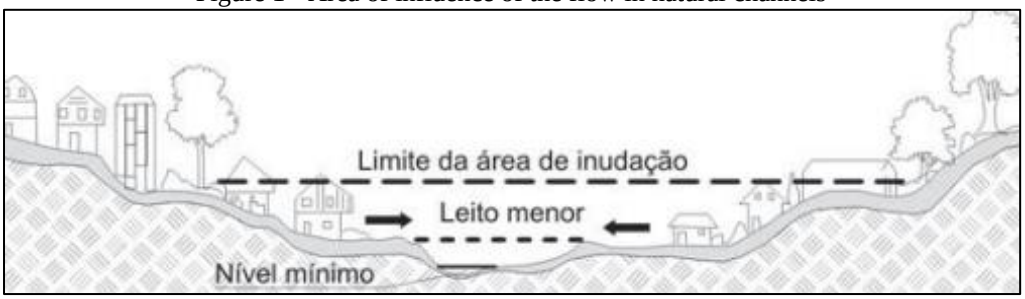
Urban rainwater management is integrated into urban water management, which considers water supply, sanitary sewage, water quality from water sources, occupation of riverside areas, among others. All these characteristics are linked to urbanization, and aim to achieve environmental health and conservation (Tucci, 2008).

The management of this system is correlated not only to the physical part of drainage, but specifically to the processes that constitute these systems, in order to improve costs and reduce environmental damage, without the system ceasing to perform its function efficiently and safely, avoiding disasters in the urban environment and downstream of it (Henriques, 2014).

According to Butler and Davies (2011), drainage systems are fundamental for developed urban areas because of the relationship between human activities, demographic expansion and the hydrological cycle, intervening in the quality of the water in these systems.

Tucci (2006) shows the problems related to unbridled use in regions close to bodies of water (Figure 1), especially when riverine floods occur, as this type of disaster can happen naturally through hydrological factors. However, these facts are consequences of urbanization, soil sealing, drainage channeling and obstruction of the latter. The impacts caused by these activities are material and human damage, with a predominance of diseases that are transported by water, interruption of economic activities, and contamination of water sources by the release of pollutants, etc.

Figure 1 - Area of influence of the flow in natural channels



SOURCE: Tucci (2008)

From the problem involving the urban drainage of rainwater, there is the duty to suggest control methods, following the current legislation, structuring and non-structuring measures and Master Plans. An important point in this scenario is the segmentation of activities, according to the area of influence of the hydrographic and urban basins (Table 2).

Table 2 - Breakdown of water management by basin

SPACE	DOMAIN	MANAGERS	INSTRUMENT	FEATURE
Watershed	State or federal	Committee and Agencies	Basin Plan	Management of the quantity and quality of water in the rivers of the river basin, without transferring impacts
Municipality	Municipality or Metropolitan Region	Municipality	Urban Master Plan and Integrated Plan for Sewerage, Urban Drainage and Solid Waste	Minimize the impacts within the city, in small urban basins and do not transfer to the river system.

Even with the information included in the table, control in the management of urban rainwater can also be done through civil interventions, for example, the construction of swimming pools as a method of damping, infiltration ditches, pavements that allow rainwater to percolate, in addition to the use of sensors and equipment that launch warning signals. However, all these tools have to be related to Rainwater Plans, as this is a very important mechanism in urban drainage management (Cárdenas-Quintero and Carvajal-Serna, 2021).

This plan must be dependent on the Master Plan of each municipality. It should also be related to other plans, especially those surrounding environmental sanitation, when dealing with situations related to water supply, sanitary sewage, solid waste management and urban cleaning, urban rainwater drainage, and primarily the environment (Tucci, 2006).

The Rainwater Plan, as described by Tucci (2001) and Tucci (2006), encompasses a series of essential components for the effective management of urban drainage water, encompassing the rainwater policy, structural and non-structural measures, as well as products and programs for monitoring and

continuous improvement. This plan also aims to create diverse scenarios and improve access to information for the population, emphasizing the importance of dialogue between the various agents involved in the search for solutions to the challenges faced in urban drainage.

The concern with the management of drainage waters and the sustainable development of cities has been growing, highlighting the need for urban planning that minimizes risks to the population. Silva (2005) points out that urban drainage transcends the technical limits of engineering, involving the adoption of measures that reduce damage to the environment and the population, especially in relation to floods. The concept of urban drainage, therefore, evolves from the need to channel rainwater to natural tributaries, in the face of the increasing impermeabilization of the soil by urbanization.

Caminha (2014) addresses the use of unconventional drainage systems as a complement or alternative to conventional macrodrainage systems, which may be inadequate due to irregular land use. These innovative structural solutions seek to improve control over the quality of drained water, avoiding pollution of water bodies. However, the management of drainage systems in large urban centers has often been neglected, resulting in negative impacts on both the environment and the population.

Souza (2005) and other scholars point out that the way urban drainage has been conducted in large cities, especially with soil waterproofing and solid waste dumping, negatively alters the surface runoff regime and compromises the quality of aquatic systems. The pollution generated and transported by this stormwater affects not only water bodies, but also the quality of urban life, emphasizing the need to integrate the management of the qualitative impacts of drainage water into urban planning practices to promote sustainable development.

MANAGEMENT MEASURES

The measures used in the planning and management of urban drainage can be determined in three spheres: hygienist, demonstrated until the year 1970 by channels used in the transfer of water from upstream to downstream; corrective or compensatory, represented between the 70s and 90s in the quantitative damping of drainage and control of the impact from the quality of rainwater; and sustainable, which has been studied since 1990 and having as its main aspect the planning of the use of urban space, which must obey the natural procedures of runoff and administration of pollutants, together with the sustainable development of rainwater runoff through the rehabilitation of infiltration areas (Forgiarini *et al*., 2007).

According to Baptista *et al*. (2005), the hygienist solutions for urban drainage, which are also called traditional or classic, only shift the problems from upstream to downstream, aiming at the quantitative solution and causing irreparable problems for the receiving soil and water body. While the corrective or compensatory solution is linked to the techniques of Best Management Practices (BMPs),

which gained impact by being disseminated and practiced worldwide for the management of rainwater runoff, it was nevertheless replaced by a solution that meets sustainability in a more efficient way (Forgiarini *et al*., 2007).

The solution with a sustainable questioning wants to be added to the concepts of sustainability, reducing the disturbances to natural and social procedures. In addition to limiting maintenance and expansion of infrastructure, this technique integrates the drainage system with various social and environmental activities, serving as parameters for the recognition of the level of sustainability (Cruz *et al*., 2007).

The Sustainable Low Impact Development (LID) techniques of Canada and the USA, known in Brazil as Low Impact Urban Development, have generated new technologies that relate urban drainage to sustainable development through the installation and improvement of existing systems, aiming at resizing for the use, infiltration and evaporation of rainwater, as well as reducing the impacts arising from unplanned urbanization. Currently, the LID acts directly in the planning of urban projects and environments, seeking to conserve the hydrological process and natural resources, as well as to protect the soil and waters from possible pollution (Souza, 2005; Cruz *et al*., 2007).

Several studies have shown new definitions of urban drainage projects, which add engineering techniques to minimize peak flows, among the techniques are maintenance in open channels, retention reservoirs and adoption of permeable areas (Canholi, 1995). Landscape, environmental and economic gains are among the positive points obtained with the management of the urban drainage system, which understands from the control of the frequency, duration and intensity of precipitation, the quality of the volume runoff superficially (Souza, 2005).

MANAGEMENT CHALLENGES

Realizing the limits of traditional solutions is one of the first and most important steps to advance in the growth of urban drainage management, but this fact alone is not enough.

Studies on the subject in Brazil have grown in the adjustment and development of more integrated drainage solutions seen from a global point: urban integration, with an integral view of the hydrographic basin, the watercourse as an urban element, the effects of water quantity and quality, among other issues. However, several characteristics need to be improved, which can be highlighted according to Souza (2013):

- Change the result of research in practice: the technical-institutional environment has also realized the limits of traditional solutions, but the absence of manuals with the new alternatives presenting parameters and methodologies that can be easily incorporated makes it difficult to apply;

- Technical-institutional fortification: for the appropriate treatment of drainage, it is necessary to provide a basis to the municipal bodies responsible for rainwater drainage, taking into account: information support: hydrological and water quality monitoring networks, network registration, etc.; the technical qualification to act in a new point of view of urban drainage, with a multidisciplinary profile; the development of an accessible and functional information support for management: maps of indicators with intervention priorities, risk maps; the commitment of society in the stages of designing drainage solutions, since this system relates directly to the population, either due to the problems it causes or due to the visual impact;
- The implementation of new techniques requires an opinion of their operation over the years, improvement of maintenance and monitoring routines, evaluation of all costs, among others. This situation faces obstacles due to the discontinuity of studies on new solutions in the country, usually related to a project valid for 2 to 3 years or to a master's or doctoral study, being forgotten after its completion;
- Academic studies have little visibility and are not evaluated on a real scale: it is necessary to assemble units for certification on a real scale of use;
- The perception, design and dimensioning of drainage structures are related to imprecision that usually ends up in the real lack of knowledge of the functions of the systems. Monitoring and modeling in urban areas are important for correct intervention;
- Even dealing with integrated solutions, drainage treatment still happens in a fragmented way, with emphasis only on quantitative characteristics. It is necessary to effectively integrate urban characteristics, verify water quality situations, society's conception related to drainage solutions, among other characteristics;
- Efficient incorporation of the study: the spaces for discussion in technical-scientific associations are still divided. To exemplify, while ABES (Brazilian Association of Sanitary and Environmental Engineering) addresses water quality situations, ABRH (Brazilian Association of Water Resources) debates quantity issues.

FINAL CONSIDERATIONS

Finally, a literature review research was conducted, addressing selected studies that contemplated the discussion of measures and solutions related to the management of urban drainage systems, especially in Brazil. Qualitative analyses were carried out, focusing especially on the comparison of data and parameters related to urban drainage systems. Thus, the main conclusions derived from this review are explained in the following paragraphs.

In recent years, the country has advanced in its thoughts on drainage management and urban rainwater management, especially in academic articles – studies on technical solutions and integrated approaches to urban planning – and in legal circumstances, with the addition of drainage in the basic sanitation scenario. However, there is an enormous difficulty in relating academic knowledge with the practical performance of this system.

In response to the motivating question, it is necessary to take into account the possibilities of progress in the treatment of drainage, with emphasis on taking advantage of the experiences of other countries in the management of drainage, while considering the particularities of Brazil, and direct transfer is not likely without the need for adaptation of technologies and techniques. It is also necessary to highlight the tools of urban policy with emphasis on Law 11.445/2007, the Municipal Plans for Urban Development and Sanitation and Program 1138, which require interaction in knowledge. Law No. 11,445 presents necessary components of sanitation for the same discussion space, however, it also presents the importance of integrating all areas of knowledge in the discussion, with emphasis on urbanism, present in several other instruments;

Government programs, especially the PAC (Growth Acceleration Program), also deserve to be highlighted because they facilitate investments in basic sanitation, even if, in the case of drainage, it is a traditional treatment. With all the research carried out, it is observed that there are still many spaces to be filled for an effective change in standards in the treatment of drainage and management of urban rainwater, whether in the conception of the advancement in academic-scientific knowledge, or in the technical-institutional conception.

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