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Risks of accidents caused by urban drainage infrastructure in Brazilian cities

Riscos de acidentes causados pela infraestrutura de drenagem urbana em cidades brasileiras

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Abstract: This study examines the vulnerability of the stormwater microdrainage system in urban environments and the risk of accidents during its maintenance and operation. Through the survey of incidents reported in public communication bodies, various types of accidents were identified, subdivided into occurrences on days of intense rain and in dry weather. The data collected from 2010 to 2018 indicate a total of 33 accidents in 26 Brazilian cities, resulting in material damages, 21 injuries, and 12 fatalities. It is concluded that deficiencies in the execution and maintenance of the microdrainage system pose serious accident risks. Merely constructing the drainage system is insufficient to guarantee its efficiency; the municipal organization chart must include operation and maintenance, with the allocation of resources, technical team, and organizational conditions for preventive and corrective maintenance and accident prevention.

Keywords: Stormwater microdrainage; Risk of urban accidents; Urban infrastructure.

Resumo: Este estudo analisa a vulnerabilidade do sistema de microdrenagem de águas pluviais no ambiente urbano e o risco de acidentes durante sua operação. Através do levantamento de ocorrências noticiadas em órgãos de comunicação pública, identificou-se diversas tipologias de acidentes, sendo subdivididas em ocorrências em dias de chuvas intensas e em tempo seco. Os dados coletados de 2010 a 2018 indicam um total de 33 acidentes em 26 cidades brasileiras, resultando em danos materiais, 21 feridos e 12 fatalidades. Conclui-se que as deficiências na execução e manutenção do sistema de microdrenagem representam sérios riscos de acidentes. É insuficiente apenas a construção do sistema de drenagem para garantir sua eficiência; o organograma municipal deve incluir operação e manutenção, com a alocação de recursos, equipe técnica e condições organizacionais para manutenção preventiva e corretiva e prevenção de acidentes.

Palavras-chave: Microdrenagem de águas pluviais; Risco de acidentes urbanos; Infraestrutura urbana.

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1. Introduction

Urban infrastructure plays a fundamental role in quality of life, and its proper maintenance is essential to ensure the well-being of the population in Brazilian cities. Stormwater drainage is a key aspect of infrastructure, particularly in humid tropical cities. However, drainage-related issues, such as open manholes and storm drains, can pose significant risks to pedestrians and road users.

Proper maintenance of drainage systems, including manholes and storm drains, is crucial to the population's quality of life (TASSI *et al*., 2016). Open manholes and storm drains can cause serious and even fatal accidents for both pedestrians and drivers, especially during periods of heavy rainfall.

For the sake of clarity, some key concepts will be reviewed here. The urban stormwater system can be subdivided into micro-drainage (gutters, gutter drains, culverts, and manholes) and macro-drainage (canals, rivers, and streams). Gutters are channels located along the edges of streets that collect rainwater from the pavement and sidewalks. Gutter drain are openings that receive water from the gutters and direct it to the culverts; they may consist of a horizontal grate or a vertical curb inlet, commonly referred to in some cities as a curb drain. Manholes are underground inspection chambers connected to gutter drain, allowing access for the inspection and cleaning of rain gallery and culverts.

Strictly speaking, culverts are transverse pipes installed beneath roadways to allow the flow of small streams across public streets. However, in brazilian everyday language and in the media, the term "culvert cover" is commonly used to refer to the round metal or concrete covers seen in the middle of streets or on sidewalks. In the technical language of stormwater drainage engineering, these are actually manhole covers. Nonetheless, in this article, the term "manhole cover" will be used whenever it appears in the referenced literature.

The objective of this article is to analyze and discuss the risks of accidents associated with urban drainage systems in Brazilian cities during their operation, focusing on the impacts on pedestrians and other users of public thoroughfares in everyday urban life.

2. Methodology

This study adopts a descriptive and exploratory approach, based on document analysis and case studies, to investigate the risks of accidents associated with urban micro-drainage elements in Brazilian cities. The focus is on components such as manholes, gutter drain, and gutters. The following section outlines the procedures adopted, enabling the replication of the methodology in other urban contexts:

2.1 Empirical Data Collection

A systematic survey of accident records involving elements of the micro-drainage system was carried out for the period from 2010 to 2018. The sources of information used included:

Online news platforms, including major news portals such as G1, UOL, Globo.com, among others

Publicly available technical reports from municipal governments and urban infrastructure agencies

Photographic and video records of accidents, made available through news reports and digital media.

The search terms included combinations such as "open manhole accident," "fall into manhole," "gutter drain accident," among others, with filters applied by location and year.

2.2 Event Selection and Categorization

A total of 56 event records were initially identified. After screening for duplicates and data inconsistencies, 33 valid records remained. These were classified according to the following criteria:

- Weather conditions at the time of the accident: dry weather or heavy rain.
- Nature of the accident: pedestrian fall, motorcyclist/cyclist accident, drowning, suction, etc.
- Event location: lane, sidewalk, intersection, etc.
- Consequence: minor injuries, serious injuries, death, or property damage.

2.3 Database Structuring

All data were organized in a Microsoft Excel 365 spreadsheet, with columns for date, location, type of device involved, weather condition, apparent cause of the accident, outcome, and source of information.

2.4 Technical and Regulatory Framework

The technical analysis was based on standards and specialized literature on urban drainage, including:

- Technical publications such as (2014), Miguez *et al.* (2015), Baptista *et al.* (2011);
- Regulatory standards from the Ministry of Labor (NR-15) and federal legislation (Law No. 14,026/2020).

2.5 Qualitative and Quantitative Analysis

The risk assessment was conducted using a descriptive qualitative approach, based on typologies of accidents related to urban micro-drainage, as discussed by Miguez et al. (2015) and Canholi (2014), who classify risks according to their origin (such as design, maintenance, and usage failures). In parallel, a descriptive quantitative analysis was applied, drawing methodological inspiration from studies such as those by Uddin et al. (2013) and Butler et al. (2018), which advocate the use of empirical metrics for assessing performance and risks in urban infrastructure.

The main metrics considered were:

- Frequency of accidents by type of drainage device (Melo *et al.*, 2016);
- Geographic and temporal distribution of occurrences (Miguez *et al.*, 2016);
- Severity of consequences (injuries, fatalities, material damage), based on a categorization similar to that used by Ghandour *et al*. (2020) in analyses of vehicle-related accidents;
- Identification of contributing factors, such as lack of maintenance, structural failures, or obstructions, according to approaches proposed by Hoang and Fenner (2016) and Papadimitriou et al. (2019) in the evaluation of risks associated with urban infrastructure.

3. Results and discussion

3.1 Risk Identification

There are three main categories of accidents associated with the drainage system (Table 1): work-related accidents during construction, work-related accidents during maintenance, and accidents involving people or vehicles (such as bicycles, motorcycles, and cars). The latter are often caused by inadequate sizing, wear and tear, breakage, or improper positioning of drainage elements.

Table 1– Risks for Pedestrians, Cyclists, Motorcyclists, and Automobiles in Dry and Rainy Weather.

Risks in the Urban Micro-Drainage System		
Days of Heavy Rainfall		
Cause	Consequence	Risk
- Rainfall Exceeding Design Capacity	Widespread Flooding	Drowning Being Swept Away by Water Fall into a Manhole Suction through a gutter drain
- Obstruction by Sediment or Waste - Structural Failure in the System	Localized Flooding	
Dry Weather		
Cause	Consequence	Risk
Broken manhole slab or missing cover on the sidewalk	Risk to pedestrians	Fall into manhole
Broken or missing manhole cover on the roadway	Risk to bicycles, motorcycles, and cars	Loss of vehicle control Fall into manhole
Uneven manhole cover on the roadway	Risk to bicycles, motorcycles, and cars	Loss of vehicle control
Broken gutter drain grate	Risk to bicycles and motorcycles Risk to pedestrians	Leg trapped in the grate Loss of control
Damaged manhole slab concrete	Exposed metal ends	Laceration of lower limbs

		Deep cuts in case of a fall

Source: Authors (2025).

According to Table 1, during periods of heavy rainfall, the consequences of an inadequate or undersized drainage system can be extremely severe, leading to widespread flooding and potentially endangering lives. For instance, in the context of rainfall exceeding design capacity, Miguez *et al*. (2016) highlight the risks of drowning, being swept away by water, falling into manholes, and suction through gutter drain.

In dry weather, the risks are different but no less significant. Inadequate maintenance and structural deterioration of the drainage system can pose various hazards to pedestrians, cyclists, motorcyclists, and drivers. The works of Canholi (2014) and Miguez *et al*. (2015), for example, emphasize falls into manholes resulting from broken or missing slabs or covers, both on sidewalks and on roadways. Additionally, broken gutter drain grates may trap pedestrians' and motorcyclists' legs, while uneven manhole covers can cause vehicles to lose control.

These risks are exacerbated by the lack of clear standardization in the design and maintenance practices of drainage systems, a topic explored by Baptista *et al*. (2011). It is also essential to consider the role of solid waste and sediment in obstructing the drainage system, which can result in localized flooding even during rainfall events that do not exceed the design threshold.

These findings underscore the need for a holistic approach to urban drainage system management, one that addresses both preparedness for extreme weather events and the regular, proper maintenance of the system. In this regard, the studies by Tassi *et al*. (2016) and Coutinho *et al*. (2018) provide valuable insights into effective strategies for mitigating these risks and improving the resilience of urban drainage systems.

3.2 Analysis of Consequences

The analysis of the consequences of accidents associated with urban drainage in Brazil reveals a series of significant concerns. These accidents, often fatal, have been documented through media reports and personal testimonies, as there are no official statistics available for this category of incidents (TASSI *et al*., 2016).

A particularly alarming example occurred in 2016 in Guaporé (RS), where a child was fatally swept away by stormwater after falling into a drainage pipe (Miguez *et al*., 2015). A similar incident took place in Maceió (AL) in 2018, when two workers were dragged by a flood while attempting to clear a manhole (Baptista *et al*., 2011).

In addition, inadequate sizing or damage to drainage elements, such as gutter drain, can lead to severe consequences, as evidenced by the cases of three adults who drowned and one who was seriously injured between 2013 and 2016 in Anápolis (GO), Natal (RN), Morrinhos (GO), and São Luís (MA) (Canholi, 2014).

Cases of children being swept away and sucked into poorly designed gutter drain were documented in Manaus (AM), Alto Paranaíba (MG), and Toritama (PE) between 2016 and 2018, resulting in the loss of these young lives (Melo *et al*., 2016). Furthermore, in 2013, a child in Manaus (AM) was injured after being sucked into a gutter drain and dragged for over 400 meters until reaching a stream (COUTINHO *et al*., 2016).

During dry periods, accidents also occur due to negligence in the execution of drainage works or the lack of proper maintenance (Miguez *et al*., 2015). Figure 1 illustrates a common vulnerability in many Brazilian cities, where the opening of a gutter drain is excessively large, increasing the risk of accidents (TASSI *et al.*, 2016).

Figure 1 – Excessively open manhole producing a hazardous situation.

Source: Adapted from Moura (2015).

Canholi (2014) highlights that wide openings in gutter drain can result in pedestrians, cyclists, and even vehicles being swept in or falling under extreme conditions. Melo et al. (2016) further emphasize the need for proper design of these micro-drainage elements in order to minimize accident risks and ensure user safety. Therefore, it is essential to implement technical standards that regulate the sizing of these structures, aiming at accident prevention and public safety.

Figures 2 and 3 illustrate incidents that occurred in the cities of São Vicente (SP) and Volta Redonda (RJ), where pedestrians, upon stepping on gutter drain grates with compromised structural integrity, had their legs trapped due to the rupture of one of the bars. Firefighters were required to safely remove the victims. Similar incidents were reported in the municipalities of Olinda (PE), Macapá (AP), Rio de Janeiro (RJ), and Cariacica (ES). Injuries included deep cuts, abrasions, and, in some cases, knee sprains.

Figures 2 and 3 – Accident while walking on the street resulting in leg trapped in the gutter drain grate.

Source: Adapted from Xavier (2018) e G1 (2017).

According to Figures 2 and 3, safety issues related to gutter drain grates with compromised structural integrity are concerning and have been discussed in the technical literature (Tassi et al., 2016). Damaged grates can lead to falls, serious injuries, and even fatal accidents (Melo et al., 2016). Studies indicate that inadequate maintenance, the quality of materials used, and exposure to high loads are factors that can affect the durability and strength of the grates (Baptista et al., 2011).

The deterioration of manhole covers, which exposes reinforcement bars and creates a significant risk for pedestrians and cyclists, remains a continuous challenge in public infrastructure management (Figure 4).

Figure 4 – Damaged manhole cover with exposed reinforcement bars: serious risks for pedestrians or cyclists.

Source: Authors (2025).

Exposed reinforcement bars can cause deep abrasions (Uddin et al., 2013) and illustrate the need for regular maintenance and infrastructure monitoring to prevent incidents (Butler et al., 2018). Sustainable urban drainage systems and green infrastructure can minimize these risks while providing environmental and aesthetic benefits (Hoang and Fenner, 2016).

The absence or damage of manhole covers is a recurring problem in many Brazilian cities, whether on roadways or sidewalks (Figure 5). Missing covers can cause serious accidents involving pedestrians. For example, in 2014, a woman suffered spinal injuries and was diagnosed with tetraplegia after falling into a manhole in Arraias (TO). Additionally, six other incidents involving falls into manholes resulting in injuries, although less severe, were reported in São Paulo (SP), Cariacica (ES), João Pessoa (PB), Boa Vista (RR), Vitória (ES), and Bauru (SP) between 2013 and 2017.

Figure 5 – Manhole missing cover, posing a risk to pedestrians or vehicles.

Source: Authors (2025).

The absence or damage of manhole covers on roadways constitutes a significant traffic hazard, with the potential to cause serious accidents. Vehicles traveling at high speeds encountering such obstacles may lose control, resulting in collisions and crashes (Singh, 2022).

Recent studies by Ajao and Oludamilare (2023) emphasize the importance of maintaining the integrity of transportation infrastructure components, especially in a future scenario of increasing adoption of autonomous vehicles. According to these authors, infrastructure deficiencies, such as uncovered manholes, can compromise the safe operation of these vehicles, exacerbating the severity of accidents.

Reports of eight traffic accidents caused by missing or broken manhole covers have been identified in cities including Campo Grande (MS), São Luís (MA), Manaus (AM), Divinópolis (TO), Brasília (DF), Cuiabá (MT), and Rio de Janeiro (RJ). Among these, five accidents resulted in serious injuries and one death, all involving motorcyclists.

In this context, Yong et al. (2023) discuss the importance of efficient street lighting and accident monitoring systems. Early detection of manholes without covers or with damaged covers can be an effective preventive measure to reduce the occurrence of accidents.

According to Figure 6, the unevenness between the manhole cover and the asphalt poses a significant risk for traffic accidents, especially for motorcyclists. When crossing these uneven surfaces at high speeds, motorcyclists may lose control, resulting in falls and collisions with other vehicles, poles, or trees (Gomes, 2012; Nasri and Aghabayk, 2021). In 2017, two motorcyclists lost their lives in accidents related to uneven manhole covers in Goiânia (GO) and São José do Rio Preto (SP).

Figure 6 – Accident involving a motorcycle passing over a drainage hole without a cover.

Source: G1 (2012).

In Goiânia, a victim fell after passing over a manhole cover submerged in water with a 6 cm unevenness and was subsequently run over by another motorcyclist. In São José do Rio Preto, a motorcyclist swerved while crossing an uneven manhole cover and collided with a tree.

Finally, Ghandour et al. (2020) employed a machine learning approach to analyze factors associated with fatal traffic accidents.

These studies highlight the need for regular maintenance and precise monitoring of public road conditions, including manhole covers, to prevent accidents and improve traffic safety.

3.3 Investigation of Contributing Factors

Accident investigation is a structured process aimed at identifying the root cause of an accident and developing strategies to prevent similar occurrences in the future. Table 2 presents the typical causes of accidents in Brazil based on 31 publicly available technical reports.

Table 2 – Accidents in the Urban Micro-Drainage System Found in Brazil.

Accidents in the Urban Micro-Drainage System				
Days of Heavy Rainfall				
Cause	Risk	Locations	Dates	Consequences
Rainfall Exceeding Design Storm	Drowning	Maceió (AL) Guaporé (RS)	01/27/2018 02/09/2016	3 deaths
	Being swept away			
	Fall into a manhole			
Obstruction by Sediment or Debris	Suction through gutter drain	Toritama (PE) Alto Paranaíba (MG) Anápolis (GO) Natal (RN) Morrinhos (GO) Manaus (AM) São Luiz (MA)	02/19/2018 12/02/2017 10/30/2016 03/21/2015 17/02/2014 11/09/2013 19/05/2013	6 deaths and 2 injured
Structural failure in the system				
Dry Weather				
Cause	Risk	Locations	Dates	Consequences

Broken manhole slab on the sidewalk or missing cover	Fall into manhole	Arraias (TO) São Paulo (SP) Cariacica (ES) João Pessoa (PB) Boa Vista (RR) Vitória (ES) Bauru (SP)	09/01/2014 12/18/2013 03/05/2013 01/22/2013 09/24/2017 10/02/2017 06/11/2017	7 injured
Broken or missing manhole cover on the roadway	Loss of vehicle control	Campo Grande (MS) São Luiz (MA) Manaus (AM) Divinópolis (TO) Brasília (DF) Cuiabá (MT) Rio de Janeiro (RJ)	06/04/2015 05/30/2015 04/11/2015 10/17/2013 11/19/2012 05/24/2012 05/10/2010	5 injured, 1 death, and property damage
	Fall into manhole			
Uneven manhole cover on the roadway	Loss of vehicle control	Goiânia (GO) São José do Rio Preto (SP)	11/21/2017 03/29/2017	2 deaths
Broken gutter drain grate	Leg trapped in grate Loss of control	Olinda (PE) São Vicente (SP) Macapá (AP) Rio de Janeiro (RJ) Cariacica (ES)	04/20/2018 02/17/2018 01/24/2018 09/22/2017 03/01/2015 12/02/2011 09/18/2011	7 finjured

Source: Authors (2025).

Traffic accidents resulting from damaged or inadequate drainage infrastructure have been the focus of various studies, particularly due to the association of these accidents with heavy rainfall conditions, blockage of drainage systems, and structural failures in manhole covers and gutter drain grates (Uddin et al., 2013; Butler et al., 2018).

Excessive rainfall exceeding the design storm can overload drainage systems and create hazards on urban roads, as existing infrastructure may be insufficient to handle extreme water volumes (Hoang and Fenner, 2016). This phenomenon is directly correlated with traffic risks, as noted by Papadimitriou et al. (2019), who identified road infrastructure, including drainage systems, as a significant risk factor for accidents.

Obstruction by sediment or debris is another concerning cause. Uddin et al. (2013) argue that effective management of public infrastructure assets, such as drainage systems, is crucial for traffic safety by preventing accidents caused by blockages and inadequate maintenance.

Structural failure in drainage systems whether in the manhole slab on sidewalks, manhole covers on roadways, or gutter drain grates poses a direct risk to the safety of pedestrians, cyclists, and drivers (Butler et al., 2018). The unevenness of manhole covers on roadways, in particular, presents a significant hazard for motorcyclists, potentially leading to loss of control and serious accidents (AJAO & OLUDAMILARE, 2023; SINGH, 2022).

he responsible authorities need to focus on the proper construction and maintenance of these systems, as well as on public education regarding the risks associated with damaged or inadequate infrastructure (Yong et al., 2023). The implementation of efficient monitoring systems, such as the "Smart Street Lights" proposed by Yong et al. (2023), can also play a key role in accident prevention.

3.4 Proposition of Prevention and Mitigation Measures

The research clearly reveals that Brazilian cities are facing a range of accident risks due to deficiencies in the execution of micro-drainage works and a lack of proper maintenance (Uddin et al., 2013). Failures in drainage systems are widespread across urban areas and often go unnoticed until an incident occurs.

First, authorities must invest in more effective infrastructure asset management practices to ensure that micro-drainage works are properly constructed and maintained (Uddin et al., 2013).

Second, greater emphasis is needed on the planning and design of drainage systems (Hoang and Fenner, 2016). Systems should be designed to handle extreme rainfall events and prevent blockage by debris, which can enhance safety under adverse weather conditions (Papadimitriou et al., 2019).

Third, accident data and reports should be utilized to better understand where and why accidents are occurring (Ghandour et al., 2020) in order to develop effective intervention strategies.

Finally, the implementation of advanced technologies, such as intelligent monitoring systems (Yong et al., 2023), can be crucial for identifying problems in real time and preventing accidents. Additionally, greater public awareness of the risks associated with damaged or inadequate drainage infrastructure should be promoted through educational campaigns and appropriate signage.

The challenges are significant, but with a multifaceted approach combining improved asset management practices, effective infrastructure planning, accident data analysis, and the adoption of advanced monitoring technologies, it is possible to significantly enhance safety on urban roads.

3.5 Analysis of Examples and Case Studies

There are numerous failures in drainage systems in many Brazilian cities. Araújo (2008) emphasizes the need to adhere to the Regulatory Standards of the Ministry of Labor and Employment to ensure worker safety (Baptista et al., 2011). For example, Regulatory Standard No. 15 specifies the conditions under which operations and activities are considered unhealthy, including exposure to humid environments (Brazil, 2023).

Baptista et al. (2011) discuss the application of compensatory techniques in urban drainage, which can help address insufficient drainage issues and prevent flooding. These techniques include the use of nature-based solutions, such as rain gardens and infiltration trenches, which are effective in managing urban stormwater and can help prevent accidents associated with inadequate drainage (Melo et al., 2014; Miguez et al., 2016).

Furthermore, the analysis of accident cases, such as those recorded in Volta Redonda (G1, 2017) and Cuiabá (Gomes, 2012), reveals the need for improvements in the safety and maintenance of drainage systems.

Many cities have developed a Drainage and Stormwater Management Manual, which provides technical guidelines and recommendations for the design and implementation of urban drainage systems. The manual from the city of São Paulo, for example, recommends an inspection procedure for micro-drainage devices at least once every 60 days (São Paulo City Hall, 2012). This recommendation is excellent, but medium and large cities with tens of thousands of micro-drainage devices will need to develop new inspection methodologies to meet the preventive maintenance frequency proposed in the manual.

The complexity of urban drainage problems requires an integrated approach that combines the application of compensatory techniques, strict occupational safety regulations, and effective urban planning. Therefore, it is crucial to invest in appropriate urban drainage solutions that are efficient, safe, and sustainable. Additionally, awareness and education on the importance of drainage system maintenance can contribute to accident prevention (MACHADO *et al.,* 2015).

3.6 Examination of the Role of Governments and Other Stakeholders

In the context of preventing and mitigating risks associated with urban drainage, a wide range of actors play crucial roles, as described below:

Canholi (2014) emphasizes the primary responsibility of governments in setting guidelines and regulations for the effective management of risks related to urban drainage. The author argues that proper urban planning and efficient stormwater management should be the pillars of public policies in this domain.

Complementing Canholi's perspective, Miguez et al. (2015) reiterate the need for government commitment to innovation and investment in infrastructure and technology. According to these authors, sustainability can only be achieved through a committed and proactive governance approach.

These views are supported by Law No. 14,026/2020, considered the new legal framework for sanitation, which establishes national guidelines for basic sanitation, and by Regulatory Standard No. 15 (Brazil, 2023), which identifies unhealthy activities and operations.

On the other hand, Cavalcanti, Lago, and Barkokébas Junior (2017), in their study on risk analysis in water pumping stations, highlight the role of public utility companies and other private sector actors. According to them, these groups,

responsible for the design, construction, and maintenance of drainage infrastructure, share a significant portion of the responsibility in managing these risks.

Furthermore, research by Melo et al. (2014) and Melo et al. (2016) on urban stormwater management techniques underscores the importance of local communities and civil society. These authors advocate that education and awareness among these groups can be decisive in accident prevention.

In summary, responsibility for preventing and mitigating risks related to urban drainage is multifaceted and shared. Collaboration among governments, public utility companies, the private sector, and civil society is therefore essential to ensure effective and sustainable management of urban drainage.

3.7 Evaluation of Legislation and Regulation

Some federal laws and regulatory standards are particularly relevant to the discussion on the safety of urban infrastructure:

A) Law No. 14,026/2020, known as the Legal Framework for Basic Sanitation, establishes guidelines for sanitation services, including urban stormwater drainage and management.

B) Regulatory Standard No. 15 (NR-15): A Ministry of Labor regulation that identifies activities considered unhealthy and establishes safety procedures. It covers workers involved in the construction and maintenance of urban infrastructure (Brazil, 2023).

C) Law No. 6,938/1981: National Environmental Policy, which includes guidelines for the protection and improvement of environmental quality. Although it does not specifically address urban infrastructure, it may have implications for how basic sanitation and urban drainage are conducted.

D) Law No. 12,608/2012: This law establishes the National Policy for Civil Protection and Defense (PNPDEC), which provides measures for prevention, mitigation, preparedness, response, and recovery in the face of disasters, including those that may be caused by failures in urban infrastructure.

The development and safety of urban infrastructures, particularly concerning manholes and storm drains, are issues that demand serious and meticulous attention from all stakeholders. Canholi (2014), when addressing urban drainage and flood control, argues that the first step to ensuring safety is to establish clear and specific regulations guiding the planning, construction, and maintenance of urban infrastructure.

Miguez, Veról, and Rezende (2015), while discussing urban drainage, emphasize that appropriate laws and well-defined quality standards are essential to mitigate risks associated with these infrastructures.

However, the issue of safety is not limited to the creation of regulations. Cavalcanti, Lago, and Barkokébas Junior (2017), in their study on risk analysis in water pumping stations, highlight the need for active involvement of service operators—who, being responsible for infrastructure maintenance, must strictly adhere to safety and quality standards.

Coutinho et al. (2016) bring civil society into this debate. They argue that while laws and regulations form the backbone of safety, public awareness and vigilance are equally important. According to the authors, the population needs to be educated about the risks associated with open manholes and storm drains and encouraged to report any irregularities.

Finally, it is undeniable that governments—whether municipal, state, or federal—have the primary responsibility to formulate and implement laws to ensure the safety of urban infrastructure. Public utility companies and citizens play complementary roles, respectively adhering to regulations and maintaining vigilance over potential system failures. Therefore, a collaborative approach is necessary for the effective protection of the population against risks associated with open manholes and storm drains.

4. Final considerations

The urban drainage system in Brazilian cities presents various risks, both under extreme rainfall conditions causing flooding and during dry periods with accident risks resulting from maintenance failures.

During rainy periods, there is potential for blockages caused by sedimentation or obstructions due to improper disposal of sewage and solid waste. In dry periods, negligence in maintenance and design flaws can lead to poorly sized, broken, or missing components.

Several problems have been identified in the urban drainage systems of Brazilian cities, including broken gutter drain grates, gutter drain with excessively large openings, broken manhole covers, and uncovered manholes, all of which can cause accidents involving pedestrians, cyclists, or motorcyclists.

In light of this scenario, there is an urgent need for improved management and planning of drainage systems in Brazilian cities. Effective planning for drainage system maintenance is crucial to avoid damage and hazards arising from negligence after construction. Therefore, adequate allocation of resources, technical teams, and organizational structures for preventive and corrective maintenance of these elements is essential.

Urban Geography studies need to explore economic approaches to quantify and highlight the costs associated with accidents resulting from drainage infrastructure failures. Such investigations will not only benefit the safety and well-being of the population but may also provide valuable insights to improve safety and health in the urban drainage sector, contributing to a safer and more livable city for all.

References

Ajao, Q., & Oludamilare, O. (2023). Safety Challenges and Analysis of Autonomous Electric Vehicle Development: Insights from On-Road Testing and Accident Reports. *arXiv preprint arXiv:2305.12665*.

Araújo, G. M. (2008). *Legislação de Segurança e Saúde ocupacional* - normas regulamentadoras do Ministério do Trabalho e Emprego. (2a ed.). GVC.

Baptista, M. B., Nascimento, N. O., & Barraud, S. (2011). *Técnicas compensatórias em drenagem urbana*. (2a ed.). ABRH.

Brasil (2023) NR 15 – *Atividades e operações insalubres, atualizações da norma regulamentadora número 15*, Ministério do Trabalho e Emprego.

Butler, D., Digman, C. J., Makropoulos, C., & Davies, J. W. (2018). *Urban drainage*. Crc Press.

Canholi, A. P. (2014). *Drenagem urbana e controle de enchentes*. (2a ed.). Oficina de textos.

Cavalcanti, G. L. C., Lago, E. M. G., & Barkokébas Junior, B. (2017). Sistemática para análise de risco de saúde e segurança do trabalho em estações elevatórias de água. *Revista Produção Online*, 17(1), 108-132.

Coutinho, A. P., Lassabatere, L., Montenegro, S., Antonino, A. C. D., Angulo-Jaramillo, R., & Cabral, J. J. S. P. (2016). Hydraulic characterization and hydrological behavior of a pilot permeable pavement in an urban center, Brazil. *Hydrological Processes*, 30, 4242-4254.

Coutinho, M. P., Gonçalves, D. A., Caram, R. D. O., & Soares, P. V. (2018). Áreas de inundação no trecho paulista da bacia do Rio Paraíba do Sul e nascentes do Cadastro Ambiental Rural. *Urbe. Revista Brasileira de Gestão Urbana*, *10*, 614-623.

G1 (2012) Mato Grosso. http://g1.globo.com/mato-grosso/noticia/2012/05/internauta-flagra-acidente-com-moto-que-caiu-em-bueiro-em-cuiaba.html, acesso em 10/02/2024

G1 (2017). Mulher cai em bueiro e precisa ser socorrida por bombeiros em Volta Redonda. G1 Sul do Rio e Costa Verde. https://g1.globo.com/rj/sul-do-rio-costa-verde/noticia/mulher-cai-em-bueiro-e-precisa-ser-socorrida-por-bombeiros-em-volta-redonda.ghtml, acesso em 20/03/2024

G1 (2018) Mulher passa mal ao ficar entalada em bueiro: 'Desesperada', acesso em 05/03/2022 https://g1.globo.com/sp/santosregiao/noticia/mulher-passa-mal-ao-ficar-entalada-em-bueiro-desesperada.ghtml

Ghandour, A. J., Hammoud, H., & Al-Hajj, S. (2020). Analyzing factors associated with fatal road crashes: a machine learning approach. *International journal of environmental research and public health*, *17*(11), 4111.

Gomes, W. A. (2012, Maio 24). Internauta flagra acidente com moto que caiu em bueiro em Cuiabá.

Hoang, L., & Fenner, R. A. A. (2016). System interactions of stormwater management using sustainable urban drainage systems and green infrastructure. *Urban Water Journal*, *13*(7), 739-758.

Machado, C. C., Silva, A. P., Marmello, J. S., & Paes, R. P. (2015). Riscos de acidentes do trabalho na execução e manutenções em obras de redes de drenagem e esgoto. *Engineering and Science*, 1(3), 26-34.

Melo, T. A. T., Coutinho, A. P., Cabral, J. J. S. P., Antonino, A. C. D., & Cirilo, J. A. (2014). Jardim de chuva: sistema de biorretenção para o manejo das águas pluviais urbanas. *Ambiente Construído*, 14, 147-165.

Melo, T. A. T., Coutinho, A. P., Santos, J. B. F., Cabral, J. J. S. P., Antonino, A. C. D., & Lassabatere, L. (2016). Trincheira de infiltração como técnica compensatória no manejo das águas pluviais urbanas. *Ambiente Construído*, 16, 53-72.

Miguez, M. G., Veról, A. P., & Rezende, O. M. (2015). *Drenagem Urbana: do projeto tradicional à sustentabilidade*. (1a ed.). Elsevier Editora.

Miguez, M. G., Veról, A. P., & Rezende, O. M. (2015). City growth and urban drainage alternatives: Sustainability challenge. *Journal of Urban Planning and Development*, *141*(3), 04014026.

Miguez, M. G., Veról, A. P., & Bianchini, L. (2016). Flood risk assessment and management: a case study in Rio de Janeiro. *Management of Natural Disasters*, *92*, 29-41.

Moura, C. (2015, Agosto 3). Coisas de Cajazeiras. http://coisasdecajazeiras.com.br/secretaria-de-infraestrutura-continua-servicos-de-saneamento-basico-em-cajazeiras-e-realiza-trabalhos-na-zona-rural/ acesso em 10/02/2021

Nasri, M., & Aghabayk, K. (2021). Assessing risk factors associated with urban transit bus involved accident severity: a case study of a Middle East country. *International journal of crashworthiness*, *26*(4), 413-423.

Singh, A. Road traffic accidents: An overview. *European Journal of Molecular & Clinical Medicine*, *9*(8), 2022.

Papadimitriou, E., Filtness, A., Theofilatos, A., Ziakopoulos, A., Quigley, C., & Yannis, G. (2019). Review and ranking of crash risk factors related to the road infrastructure. *Accident Analysis & Prevention*, *125*, 85-97.

Prefeitura de São Paulo. Secretaria Municipal de Desenvolvimento Urbano. (2012). *Manual de drenagem e manejo de águas pluviais*. SMDU.

Tassi, R., Piccilli, D. G. A., Brancher, S. C., & Roman, C. A. (2016). Preferências da população de diferentes estratos sociais no manejo das águas pluviais urbanas. *Ambiente Construído*, *16*, 39-52.

Tomaz, P. (2012, Agosto 11). Bocas de lobo. http://www.pliniotomaz.com.br/downloads/bocasdelobo.pdf

Uddin, W., Hudson, W. R., & Haas, R. (2013). *Public infrastructure asset management*. McGraw-Hill Education.

Yong, C. T., Hao, C. V., Ruskhan, B., Lim, S. K. Y., Boon, T. G., Wei, T. S., & Shah, S. B. I. A. (2023). An Implementation of Efficient Smart Street Lights with Crime and Accident Monitoring: A Review. *Journal of Survey in Fisheries Sciences*, 287-305.