Flood risk management in urban areas, the case of four Brazilian cities: challenges and innovations

Gestion des risques d'inondation dans les zones urbaines, le cas de quatre villes brésiliennes : défis et innovations

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RÉSUMÉ

La gestion des risques d'inondation se caractérise par sa complexité, impliquant de multiples institutions, expertises, bases de données, logistiques et gouvernances. De la planification et la préparation à la gestion des urgences, les échelles spatiales et temporelles d'action sont généralement très différentes, ce qui nécessite une bonne coordination entre les politiques et les institutions. Dans ce processus, des informations hydrologiques pertinentes et de bonne qualité sont d'une grande importance. Néanmoins, en particulier dans les villes des pays en développement, on observe des inadéquations entre la disponibilité et la qualité des informations hydrologiques et leur utilisation dans les différentes phases de la planification et de la mise en œuvre de la gestion des inondations, ce qui compromet souvent leur efficacité. Une gestion efficace des risques d'inondation devient plus pertinente face au changement climatique, car dans de nombreuses régions du monde, on s'attend à une augmentation de l'intensité des précipitations et de la fréquence des événements extrêmes, combinée à des canicules et à la sécheresse. Nous abordons ici ces questions en nous appuyant sur quatre études de cas au Brésil, les villes de Belo Horizonte, Brasília, Recife et Curitiba. Ces villes ont mis en œuvre des approches innovantes en matière de gestion des risques d'inondation, couvrant les différentes phases du processus de gestion. Dans les conclusions, nous soulignons les besoins et les directions potentielles pour l'amélioration de la gestion des inondations dans le contexte des quatre villes pays en développement.

ABSTRACT

Flood risk management is characterised by its complexity, involving multiple institutions, expertise, databases, logistics and governance. From planning and preparedness to emergency management, the spatial and temporal scales of action are usually quite different, requiring sound coordination between policies and institutions. In this process, pertinent and good-quality hydrological information is of high relevance. Nevertheless, particularly in cities of developing countries, mismatches are observed between the availability and quality of hydrological information and its use in the several phases of flood management planning and implementation, frequently compromising its effectiveness. Effective flood risk management becomes more relevant in face of climate change, since in many regions in the world increases in rainfall intensity and in the frequency of extreme events are expected, combined with heat waves and water scarcity. In the present paper, we address these issues considering four case studies in Brazil, the cities of Belo Horizonte, Brasília, Recife, and Curitiba. All these cities have implemented innovative approaches to flood risk management, covering the different phases of the management process. In the conclusions, we identify needs and potential ways for the improvement of flood management in the context of cities which exemplify challenges for flood management in the developing world.

KEYWORDS

Flood management, hydrology information, flood prevention and emergency planning

1 INTRODUCTION

Flood risk management is characterised by its complexity, involving multiple institutions, expertise, databases, logistics and governance. From planning and preparedness to emergency management, the spatial and temporal scales of action are usually quite different, requiring close coordination between policies and institutions.

In this process, pertinent and good-quality hydrological information is of high relevance. Nevertheless, particularly in cities of developing countries, mismatches are observed between the availability and quality of the hydrological information and its use in the several phases of flood management planning and implementation, frequently compromising its effectiveness.

Effective flood risk management becomes more relevant in face of climate change, since in many regions in the world increases in rainfall intensity and in the frequency of extreme events are expected, combined with heat waves and water scarcity. In developing countries, these challenges add to current issues such as socioeconomic inequalities, lack of resources for investments and good governance models, obsolescence of the water infrastructure, and deficiencies and delays in planning and adaptation to climate change impacts.

In the present paper, we address these issues considering four case studies in Brazil, the cities of Belo Horizonte, Brasília, Recife, and Curitiba. All these cities have implemented innovative approaches to flood risk management, covering the different phases of the management process. These cities are highly urbanized areas, with urban population ranging from 1.7 (Recife) to 3.0 million inhabitants (Brasília) (IBGE, 2022). The percentage of population living in favelas (shantytowns) are 2,4% in Brasília, 6,5% in Curitiba, 13.2% in Belo Horizonte, and 24% in Recife. Favelas are low-income and very dense urban areas, with densities from 20,000 to 40,000 thousand inhabitants per km^2 (IBGE, data) frequently located in flood or landslide prone areas. Due to their exposure to risk and precarious standard of living favelas are particularly vulnerable to floods.Cities usually face the drawbacks of unregulated urban sprawl that challenge the planning and management of water systems towards the principles of sustainability (Mendes & Alves, 2026; Santos & Alves, 2022).

These case studies also provide different examples of flood characteristics, with Brasília and Belo Horizonte located in small urban catchments prone to flash floods, and Recife, Curitiba and São Paulo partially located in flood plains of big rivers and subject to fluvial flooding often combined with urban flooding.

The present research is developed as part of the initiatives of the National Observatory on Water Security and Adaptive Management (ONSEAdapta, acronym in Portuguese), a National Institute of Science and Technology partially funded by the Brazilian National Council of Science and Technology (CNPq). ONSEAdapta is an interdisciplinary network of national and international researchers working on research development in different areas related to its central themes, water security and adaptation (https://onseadapta.org/en/about-2/).

2 THE CASE STUDIES: CHALLENGES AND ACHIEVEMENTS

Flood risk management involves two articulated planning processes, flood prevention and flood emergency planning processes. Urban hydrology and hydrodynamic modelling contribute to both processes through a detailed assessment of flood hazard characteristics. Flood mapping is the central product of this assessment, providing information on potentially flooding areas for various return periods, spatial distribution of flow depths, velocities and hydrodynamic risks in the flood plains (Rápalo, 2025), as well as information on flood dynamics such as lead-time for flood forecasting and flood duration (Lago et al, 2024).

For the prevention planning process, these data and information are fundamental to make flood prone areas more resilient to flood occurrences. This may involve land-use regulations to avoid the occupation or to progressively vacate flood prone areas, promoting the adoption of building flood proofing approaches and, at the catchment scale, promoting the adaptation of nature-based solutions (NbS), which may contribute to flood risk reduction. Combined with socio-economic data and characteristics of dwellings, flood mapping also enables the assessment of flood vulnerability, which is essential for prevention and emergency planning.

Innovative regulatory approaches, such as transferable building rights, joint urban development operations, payment for building rights, public funds to disaster recovery, and a national insurance framework contribute to increase flood resilience in urban areas. Apart from a national insurance programme (Gesualdo et al, 2024), all these financial and legal tools are part of the Brazilian urban legislation, although they are seldom adopted.

These processes require detailed information on the population knowledge and perception of flood risk as well

as sounding participatory processes, essential on decision making on land use regulation, adoption of NbS approaches and the acceptance of co-participating in funding NbS and flood proofing at the private scale.

Emergency planning typically involves actions in four chapters: preparedness, response, reparation and recuperation, post-event assessment and plan updating. The described flood hazard characteristics and the analysis of vulnerability to floods constitute essential information for preparedness and response. They may also play an important role in the recovery phase, providing information in the decision-making on reallocation of exposed population and on improving building resilience. Flood characteristics of past events are also important in the assessment of implemented actions during flood fighting, allowing to improve emergency plans.

Urban hydrology, combined with meteorology, provides essential data and information for forecasting and warning. This is a highly specialized area of hydrology, involving monitoring, modelling, decision making on warning and dissemination methods (Horita et al, 2017). In Brazil, at the national level, flood forecasting and warning services are provided by CEMADEN, the National Centre for Natural Disasters Monitoring and Warning. CEMADEN uses information and data provided by a dedicated national network of radars and rainfall and fluviometric stations, combined with satellite information, meteorological data and modelling provided by INPE (National Institute of Spatial Research) and INMET (National Institute of Meteorology) in forecasting (Marengo et al, 2025). CEMADEN's decision making processes on warning issuing employs forecasted and current weather conditions,threshold data to infrastructure, as weel as demographic and vulnerability data on exposed areas.

Some states and large cities in Brazil also count on their own flood forecast and warning systems as it is the case for Belo Horizonte and Recife. Emergency planning and flood fighting implementation are under the responsibility of Civil Defense, which has national, state and local level organizations. One of the national challenges regarding flood forecasting and warning is an adequate use of this information in emergency planning and implementation, particularly with respect to the level of information and preparedness of exposed population. Population warning effectiveness is still a great challenge in the national context (Saito et. al. 2019).

In Belo Horizonte, the Municipal Department for Urban Water Management and the Civil Defense Department are in charge of flood forecasting and warning. These activities are performed based on a network of rainfall and fluviometric stations locally operated, radar and satellite information, weather forecasting provided by INPE and INMET and flood warning provided by CEMADEN. Flood warning is issued through SMS, Instagram and other social media by the Civil Defense. In flood-prone areas, residents are organised into groups led by trained residents in charge of early evacuation through pre-defined escape roads. The Civil Defense and the Traffic Management departments block roads, either physically or through dynamic traffic management using dedicated traffic lights, in case of flood warning. The Waze Navigation & Life Traffic app is set up to uses flood alerts to inform drivers on the safest routes. Flooding maps are part of the land use regulation, with restrictions on the occupation of flood prone areas and requirements for the adoption of flood proofing building approaches. Nevertheless, these flood prevention measures need to be improved in the future to ensure a better control on land use in exposed areas as well as a more generalised adoption of NbS approaches in public and private areas.

Curitiba and its Metropolitan Region and its sustainable actions have been developed since 1943 with the first original master plan, involving sanitation, functional land use and soil occupation zoning, and road restructuring. The radiocentric conformation of the urban space was divided into fixed and specific zones, within the headwaters of the Iguaçu River Basin and close to water supply areas. These plans already provided guidelines for the implementation of green areas, which were improved in the 1970s.

Due to the low slope on the plain areas, the Iguaçu River developed meanders with wide curvatures and extensive floodplains. This configuration, combined with the irregular occupation of the floodplains, promoted significant flooding impacts (Ywamura, 2011). Although several sections of the river have been straightened, the terrain maintains its alluvial plain typology in addition to a channel infraestructure (20 km long) that was built for both water supply and flood control in the 1990s.

In this context, the drainage from the surrounding area flows into the corridor delimited by the Iraí/Iguaçu River and the parallel channel, enabling structural flood control and also maintaining the water level in the sand pits. These strategies were conceived during the elaboration of the Urban Drainage Master Plan for the Upper Iguaçu Basin (2002) as part of a set of actions to reduce the occurrence of floods in the city of Curitiba and municipalities in the metropolitan region. Between the original bed of the Iguaçu River and the parallel channel, an extensive "sponge" area has formed, with a complex system of wetlands and green areas (Ywamura et al, 2015).

In addition, Curitiba has dedicated efforts to a sustainable drainage system comprising NbS and gray

infrastructure. Examples are urban parks, located in major urban basins such as the Barigui River, Belém River, and Atuba River, tributaries of the Iguaçu River, which function as retention basins, increasing permeable area and buffering surface runoff in the central area of the Upper Iguaçu Basin. Despite these innovations, adaptation measures considering the impacts of climate change are still required, one that promote descentralized actions with society participation considering a broader socio-hydrology perspective (Almeida, 2024).

In the state of Pernambuco, whose capital is Recife, hydrological risk management relies on a coordinated set of non-structural measures designed to reduce the population's vulnerability to floods. At the state level, the Flood Committee for the Capibaribe and Una River Basins plays a central role in supporting monitoring activities and promoting interinstitutional coordination during critical events. The Pernambuco Water and Climate Agency (APAC) is central to this process, issuing meteorological warnings categorized as "state of attention," "state of observation," and "state of alert." Complementing APAC's technical functions, both the State and municipal Civil Defense units act directly in prevention, preparedness, and emergency response. The state currently operates 36 automatic hydrological monitoring stations, which transmit real-time data and allow alerts to be issued as soon as river levels exceed the established thresholds. Warning dissemination occurs through Civil Defense channels and APAC's social media platforms, with implementation of a mobile alert system planned for 2026.

In Recife, beyond warning systems, non-structural strategies focused on urban planning have gained prominence, especially through the creation of linear riverside parks. These initiatives are part of the Promorar Program – Urban Revitalization and Climate Resilience in Socioenvironmentally Vulnerable Areas – which aims to enhance the city's adaptive capacity to extreme rainfall events. One of its key components is the implementation of floodable parks, designed to temporarily retain excess rainwater and function as recreational areas under normal weather conditions. Such interventions increase soil infiltration, support vegetative water retention, and reduce pressure on the urban drainage network. In 2024, the first pilot floodable park was inaugurated along the Tejipió River, an area historically affected by flooding (Arruda Filho & Jacobi, 2024).

The stormwater systems in the Federal District of Brazil operate under a major challenge of socio and economic inequities, resulting in significant differences in urban planning and development among communities. The city of Brasilia, planned and built in early 60s, is characterized by great availability of green and open spaces. But the integration of NbS into traditional stormwater systems is advancing slowly and some neighborhoods face frequent floods disrupting economic activities and urban mobility. Outside Brasilia, unregulated urban sprawl led to densely populated and highly impermeable areas resulting in perfect scenarios for flood damage, not rarely including loss of lives.

Despite these concerns, some important initiatives have contributed to more reliable and sustainable solutions for stormwater systems in the region. The institutional organization for stormwater planning and management counts with a well-stablished governance including a stormwater utility (NOVACAP) and a regulator (ADASA) that integrates complex and cross-cutting policies, such as water resource management and sanitation (including water supply system, wastewater system, drainage system and solid waste management). With a specialized governance in stormwater management, some strategies have taken place such as publication of Drainage Master Plans and Manual, definition of urban planning regulations at parcel scale (requirement of rainwater harvesting reservoirs in households), urban land use planning and definition of maximum runoff discharge for new urban developments. The application of NbS integrated to traditional stormwater systems has been evaluated for specific conditions of the Federal District of Brazil (Barros *et al*. 2025, Bigonha, 2024). Recently, the government launched the SIMCURB, an Intense Precipitation Monitoring System that integrates and publishes real time data from weather stations around the region.

3 CONCLUSIONS

In conclusion, we would like to highlight some innovative approaches on flood management that may direct improvements in these case study cities, such as the use of AI in forecasting and decision-making for alerts; the use of social media for identifying and monitoring situations of risk and vulnerability, validating hydrological and hydrodynamic modelling results, post-event analysis, understanding risk perception and the population's ability to organise itself in a context of risk, among others (Horita et al, 2015); Restrepo-Estrada, 2018). We will also need innovative financial models to face increasing occurrence of urban disasters due to floods and droughts and to promote adaptation through sounding planning processes.

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