Research in Marine Sciences
Volume 8-Issue 4- 2023
Pages 342-352

Scientific review article

Investigation of dealing with urban flooding in Brazil

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Received: 2023-09-18 *Accepted: 2023-11-10*

Abstract

Urban flooding refers to the excessive accumulation of water in urban areas due to heavy rainfall or inadequate drainage systems. It occurs when the natural water absorption capacity of the soil is reduced due to urbanization, resulting in increased surface runoff. Urban flooding can include inadequate storm-water drainage systems, improper land use planning, deforestation, and climate change. Impacts of urban flooding can be severe, including property damage, disruption of transportation networks, health hazards from contaminated water, and economic losses. This paper will investigate the issue in more affected areas in Brazil and presents some strategies to dealing with the urban habitation pressure and flooding risks.

Keywords: Urban flooding; Brazil; Strategies; Flooding risks.

1. Introduction

1.1. Urban occupancy pressure in regulated areas

Urban occupancy pressure in regulated areas refers to the high demand for land and housing in urban areas that are subject to regulations and restrictions. These regulations aim to control development and ensure sustainable use of land resources. Moreover, urban occupancy pressure refers to the strain or stress placed on urban areas due to high population density and limited available space and natural resources. In regulated areas, this pressure is further intensified by government regulations and policies that control land use, development, and building codes. Regulated areas typically have zoning laws that dictate how land can be used, such as residential, commercial, or industrial purposes. These regulations aim to maintain order and prevent haphazard development. However, they can also contribute to urban occupancy pressure by limiting the amount of available land for construction and expansion.

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In fact, regulated areas often experience increased demand for housing and commercial spaces. This demand leads to higher property prices and rents as well as increased competition for limited space. It can also lead to overcrowding in existing buildings or neighborhoods. To address urban occupancy pressure in regulated areas, governments may implement various strategies. These can include:

1) Urban densification: Encouraging the construction of taller buildings or increasing the density of existing neighborhoods through infill development.
2) Mixed-use development: Promoting the integration of residential, commercial, and recreational spaces within the same area to maximize land use efficiency.
3) Affordable housing initiatives: Implementing policies or programs that provide affordable housing options for low-income individuals or families in regulated areas.
4) Transportation improvements: Enhancing public transportation systems to reduce reliance on private vehicles and alleviate congestion in urban areas.
5) Urban planning reforms: Reviewing and updating zoning regulations to allow for more flexible land use options while still maintaining appropriate standards for safety and livability.

By implementing these strategies, governments aim to balance the need for controlled development with the growing demands of an urban population. The goal is to create sustainable and livable cities that can accommodate increasing numbers of residents while preserving quality of life and minimizing negative impacts on infrastructure, environment, and social cohesion.

1.2. Main causes and impacts

Flood disasters in urban areas can arise from the occupation of floodplains or be generated by changes in land use, such as urbanization and deforestation. The main impacts of floods on the population occur when there is not enough knowledge about the frequency of water levels associated with floods and the planning of space occupation according to the risks of flooding especially for new immigrants from the city.

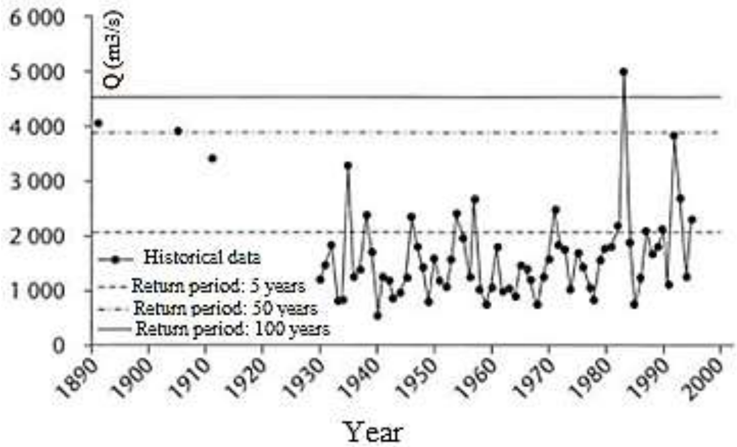

Figure 1. Maximum flood discharges in the Iguazu River in Uniao da Vitoria, a basin of approximately 25,000 km^2

A common scenario in uncontrolled urbanization is that floodplain occupation occurs over a succession of years with low flood levels that are confined within the normal margins of rivers and streams. When episodes of higher floods occur, the damage increases and authorities have to invest in relief for flood victims, followed by public demand for protection against floods. The metropolitan area of Curitiba (Paraná state, Brazil) has 2.5 million inhabitants. Most of this urban area is in the upper Iguazu River basin, which has an area of 1,000 km^2.

The greatest urban concentration is in the Belén basin and the neighboring Atuba and Palmita basins. The river has a large natural floodplain due to the small hydraulic capacity and lower slope of the river. As a result, during floods, the hydrograph is attenuated by the storage capacity of the floodplains. The regional administration legislated against the occupation of the floodplain but, in 1980, great pressure was exerted to once again occupy the area. The population invaded the green areas, building urbanizations and unauthorized housing.

Occupation of the floodplain also occurred downstream of the Iguazu River, in Uniao da Vitoria (see Figure 1). For a long period of time, floods remained below the five-year return period. The floods after 1982 caused significant damage to the community (Table 1).

Flooding is accentuated by urbanization due to the greater number of impervious areas, obstructions to flow such as bridges and garbage dumps, and man-made drainage works such as conduits and ditches. These are not natural obstacles but created to accommodate population growth and related urbanization imperatives. Generally, the land surface in small urban watersheds is composed of roofs, streets, and other impervious surfaces. The runoff flows through these surfaces to the sewers at a high speed and increases the maximum flow, the volume of surface flow and decreases the recharge of the aquifers and the evapotranspiration. Under these conditions, total runoff and maximum discharge increase, along with flood frequency (Figure 2). Porto Uniao is a city located in the Northern Plateau in the State of Santa Catarina and on the left bank of Iguazu River, bordering the city of Uniao da Vitoria, Parana.

Table 1. Losses due to floods in Uniao da Vitoria and Porto Uniao (JICA, 1995)

Year	Losses (in millions of US$)
1982	10,365
1983	78, 121
1992	54,582
1993	25,933

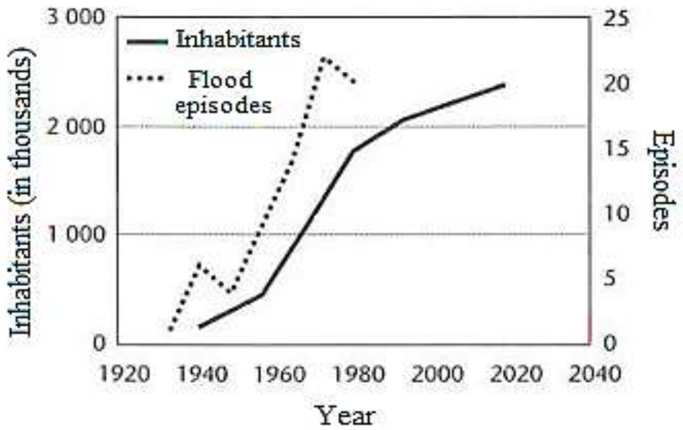

Figure 2. Increasing flood episodes in Belo Horizonte, Brazil (Ramos, 1998)

In the present case the magnitudes of the flood are multiplied up to six times due to urbanization. In addition to these effects, the surfaces through which water flows during rainy days increase the pollution load in the urban environment and downstream of rivers.

Urban flooding is generally caused by poor design of urban sewerage, which is based on the principle of draining water from urban surfaces as quickly as possible through networks of pipes and ditches that increase the risk of flooding. maximum downstream flow. There is no control of the increase in maximum discharges in the minor drainage area and most of the effects are manifested downstream, in the main drainage. To deal with this problem, municipal and state administrations carry out works such as canals in the main drainage and pipes in the secondary drainage. This type of solution helps only in transferring the flood problem from one section of the basin to another, at greater cost. In addition, the effect on water quality is greater, since the excess flow has a greater amount of solids, including metals and other toxic components.

Since the 1970s, source control of urban drainage has been developed in advanced countries through containment and retention ponds, permeable surfaces, infiltration ditches and other control measures. from the source. In developing countries this type of control hardly exists and the effects are transferred downstream in the main drainage system. The cost of controlling this impact is transferred from the individual to the public, as the country has to invest more in hydraulic structures to reduce the effects of downstream flooding.

The experience of many countries has now led to certain accepted principles in urban drainage management. These are the following:

1) A drainage assessment should be carried out for the entire basin and not confined to specific flow sections.
2) Flow control and drainage management measures should not transfer the flood effect to downstream reaches, and priority should be given to source control measures.
3) Control management should begin with the implementation in the municipalities of the Urban Drainage Master Plan.
4) Urban sewage planning should take into account future city urbanization scenarios.

5) The effects caused by the washing of the urban surface and others related to the quality of urban drainage water should be reduced.
6) Appropriate importance should be given to non-structural measures, such as floodplain zoning, insurance and real-time flood forecasting.
7) Public participation in urban sewage management should be increased.
8) Urban sewage development should be based on cost recovery.

These principles have been applied to some extent in developed countries. However, urban drainage practices in most developing countries do not satisfy these principles. The main causes are the following:

1) Urban flooding development in developing countries occurs too quickly and is unpredictable. Generally, the tendency of this urban planning is from the lower parts of the stream to the upper parts, which increases the effects of the damage (Dunne, 1986).
2) Peri-urban ecosystems and risk areas (flood plains and hillside slopes) are occupied by populations with low incomes and without a strong and stable infrastructure. The spontaneous development of houses in areas at risk of flooding can be seen in Bangkok, Bombay, Guayaquil, Lagos, Monrovia, Port Moresby and Recife. Some of the urbanizations prone to suffer landslides are Caracas, Guatemala City, La Paz, Rio de Janeiro and Salvador that was reported by World Health Organization (WHO, 1988).
3) City councils and the population usually do not have sufficient funds to meet the basic needs of water supply, sanitary facilities and sewerage.
4) The lack of adequate collection and disposal of solid waste reduces water quality and the capacity of the urban sewage network.
5) The lack of institutional organization in urban sewage at the municipal level, such as regulations, capacity building and administration.
6) Lack of law enforcement or unrealistic regulation (see Table 1).

Regulations in the city of Curitiba (Brazil) have restricted land occupation in order to preserve basins used for urban water supply and in areas prone to flooding. Urban development has invaded, to a certain extent, these areas and has increased their real estate value. The property owners adopted the following strategy: (a) clandestine development; and (b) helps the "invasion" of their lands by poor populations to break the rules and thus sell the land to the city council as a social solution that normally occurs during election years, when political pressure is greatest.

This situation occurs mainly due to the low compensation for private land owners in the regulations, as they have to keep the space unused and at the same time pay taxes for the land without obtaining any economic benefit. Lower taxes and appropriate land use that does not degrade water quality would have provided more incentives to conserve land use. In most Asian cities there is a lack of a comprehensive project organization and a clear assignment of responsibilities; adequate planning and implementation of urban land use; and the ability to cover all phases and all aspects of technical and non-structural planning (Ruiter, 1990).

1.3. Integrated urban drainage management

The planning of integrated urban drainage management is based on the aims and objectives related to the well-being of the population and the conservation of the environment. An Urban Drainage and Flood Control Master Plan (UDMP) is developed based on urban space, hydrological conditions, hydraulic network and environmental conditions to reduce flood risks. The main purposes are usually:

- The regulation of the use of floodplain zones through legislation and other non-structural measures.
- Prevention and mitigation measures for the consequences of low-frequency floods.
- Improving the quality of urban drainage water.

The conditioning factors of urban development are not discussed here, since they belong to the Urban Master Plan (UMP) but there should be a great interaction between this plan, the UDMP, the flood control plan and other plans. of the city such as the water supply and the management of solid and sanitary waste. Land use is strongly related to urban drainage and the UMP must also take into account the restrictions of the UDMP, of which the previous one is a part.

The Integrated Urban Drainage Management Plan includes:

- Non-structural measures included in the country's legislation or urban construction regulations.
- Structural measures for each sub-basin of the city in which work is planned, including environmental and economic assessments.
- Capacity building programs that offer long-term support to the Plan.

1.3.1 Non-structural measures

Non-structural measures are developed to regulate land use in floodplains and to control the impact of urbanization on drainage. Floodplain regulation typically restricts the use of flood-prone areas for new development and plans new occupancy zones in the city through the use of tax incentives.

2. Tax deduction

Facial incentives or tax deduction refer to rewards or benefits provided to individuals or communities for their active participation in flood management initiatives. These incentives can include financial assistance for implementing flood-resistant measures, tax breaks for adopting sustainable practices, or recognition for community efforts towards flood resilience.

In Estrela, a study was prepared for the city, together with the Urban Master Plan, which was included in the municipal regulations (Rezende and Tucci, 1979). After the legislation was implemented, the endangered areas were preserved and the remaining population was gradually moved to safe areas using tax incentives. These consisted of the exchange of construction zone permits for buildings in the center with flood risk areas. Moreover, flood losses and the affected population have decreased over the years since 1979.

3. Public Participation

Public participation plays a crucial role in addressing urban flooding issues. It includes involving citizens in decision-making processes related to flood management strategies, such as infrastructure development or land-use planning. Public participation ensures that community concerns are considered and helps build consensus on effective flood mitigation measures.

Uniao Vitoria and Porto Uniao (Tucci and Villanueva, 1999) are on the border of the State of Parana and Santa Calorina and have a population of about 150,000 inhabitants. This urban area is subject to frequent flooding, but in 1980 a large swamp was built to produce hydroelectric power downstream. In 1983 there was a significant flood, which had an important economic effect (60 days of flooding). The population began to blame the Electric Company (COPEL), which claimed that it was a natural flood and that the swamp did not cause any additional effects. But in 1992 another major flood occurred, smaller than that of 1983 but also with great damage and created a major conflict between the city and COPEL. The population created a non-governmental organization and a study was carried out for said organization in order to carry out a diagnosis of the flood conditions, negotiations with COPEL on operating standards and planning of the city's flood zone. The study produced some results and the negotiations improved the city's ability to cope with flooding.

Rules relating to urban drainage can also serve the objective of reducing the downstream effect of peak discharge and degradation of water quality, taking into account socio-economic conditions. The best regulations are those that increase public participation. One of the basic aspects of this type of regulation is that the new urban development maintains the maximum discharge equal to or below the existing scenario before the urbanization, limiting impervious surfaces.

3.1. Structural measures

Developing a flood control plan for urban drainage are executed by defining sub-basins, evaluating each sub-basin for the risk and the choosing suitable scenarios. Based on these individual conditions, the necessary work is planned to control these effects. Generally, structural measures are a combination of upstream reservoirs, containment ponds, dikes, river channel changes, conduits and ditches, based on available hydro-meteorological conditions, space availability, existing drainage and topography. However, they have higher costs and are only economically viable when the damage avoided is greater than the construction costs or when there are special social considerations. Non-structural measures have lower costs but are politically difficult to carry out.

3.2. Capacity building

Capacity building is also necessary in all areas. Starting with the urban drainage manual, to be used by planners and engineers to advise on the limitations of the city and the procedures accepted by it in the design of urban drainage. Capacity building is needed in communities to allow their participation.

4. Urban drainage master plan in Porto Alegre, Brazil

Porto Alegre is the capital of the State of Rio Grande do Su, in Brazil. The metropolitan area has about three million inhabitants and the municipality around two million. The city is located on the edge of the drainage basin of a river delta of about 80,000 km^2. It is protected by a system of levees and storm and pumping stations designed before 1970. The city grew from the lower part of the stream to the upper part. The actual drainage capacity is not sufficient to discharge the upstream increase in the volume and maximum flood value in some parts of the city.

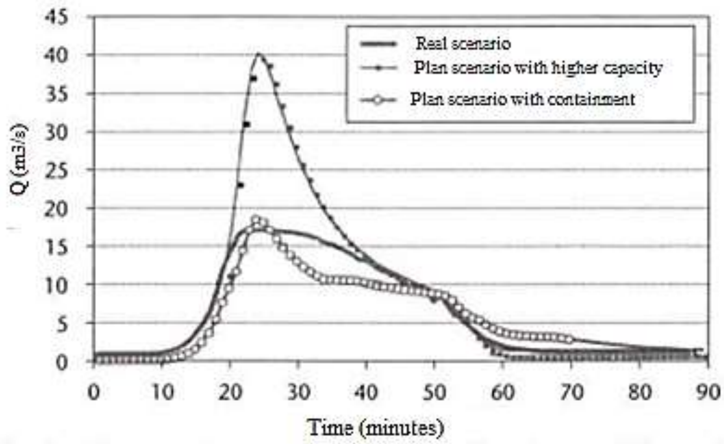

Figure 3. Hydrogram for the scenarios (future scenarios with 10 years of storms) of basin A (IPH, 2001).

The municipality of Porto Alegre covers an area of about 400 km^2 and has 26 basins. The Urban Drainage Master Plan was formulated in phases. The first of these was the proposal of non-structural measures such as legislating for new developments. The second part consisted of an examination of the design capacity of the drainage of storm precipitation over the basin and being pumped out from within the levee system, and the Plan for six major sub-basins of the city. The non-structural measures consisted of (a) new legislation on source control for housing developments, which has been implemented since March 2000; (b) capacity building in the form of urban drainage training, equivalent to an engineering degree; and (e) the preparation of a design manual. The municipality already had a department for the development and maintenance of urban drainage. The structural measures took place in the form of the Urban Drainage Plan for six basins (Tucci and Porto, 2000).

For example, the Areia basin has an area of 12 km^2 and a high population density. There is a pumping station to drain the lower basin. The drainage from the upstream basin runs inside a pressure pipe (which is located below the airport corridors and cannot be increased without significant cost) to the Jacui Delta. The basin is divided into eleven sub-basins and the study scenarios were created based on the actual occupation and that projected by the Urban Development Plan.

Increasing the pipe capacity along the main drainage system would increase the maximum flow to 140 m^3/s and would cost US$14 million without taking into account downstream impact. The use of containment ponds in the main drainage system in some public open spaces would cost US$8 million and the maximum flow would be 42 m^3/s. Figure 3 shows the hydrographs for these scenarios in one of the basins.

In the case of simulations for the prediction of runoff frequencies, it is of great importance to have sufficiently long precipitation data series, at least three times the length of the return periods of interest. The optimal rain gauge network for such operations would have a spatial resolution of between 0.1 and 1.0 km^2 and a temporal resolution of the order of 1 to 5 minutes.

An urban drainage master plan in flooding areas is a comprehensive strategy that aims to manage and mitigate the impacts of flooding in urban areas. It involves the assessment of existing drainage systems, identification of flood-prone areas, and the development of strategies to improve drainage infrastructure and reduce flood risks.

The key components of an urban drainage master plan in flooding areas may include (Pryl, 2001):

1) Flood risk assessment: This involves analyzing historical flood data, mapping flood-prone areas, and assessing the vulnerability of critical infrastructure to flooding.
2) Drainage system evaluation: The existing drainage infrastructure is assessed to identify its capacity, condition, and any deficiencies. This evaluation helps determine if upgrades or repairs are needed.
3) Storm-water management: Strategies for managing storm-water runoff are developed to reduce the volume and velocity of water entering the drainage system during heavy rainfall events. This may include implementing green infrastructure solutions such as rain gardens, bioswales, or permeable pavements. For more information, Bioswales are landscape features that collect polluted storm-water runoff, soak it into the ground, and filter out pollution. Bioswales are similar to rain gardens but are designed to capture much more runoff coming from larger areas of impervious surfaces like streets and parking lots (https://urbangreenbluegrids.com/measures/bioswales/)
4) Floodplain management: Measures are implemented to regulate development within flood-prone areas, including zoning regulations and building codes that require elevated structures or flood-resistant materials.

5) Emergency response planning: Protocols are established for responding to flood events, including early warning systems, evacuation plans, and coordination with emergency services.
6) Public education and awareness: Community engagement programs are developed to educate residents about flood risks, proper waste disposal practices, and ways they can contribute to reducing flooding through responsible water management.
7) Long-term maintenance and monitoring: Regular inspections and maintenance activities are scheduled to ensure the continued functionality of drainage infrastructure over time. Monitoring systems may also be implemented to track rainfall patterns and water levels in critical areas.

By implementing an urban drainage master plan in flooding areas, cities can better manage their storm-water runoff, reduce flood risks for residents and businesses, protect critical infrastructure from damage, and enhance overall resilience against future climate change impacts.

Conclusion

Urban flooding is one of the main threats to cities. Most of the existing public policies in developing countries are not technically, socially or economically adequate. Integrated urban drainage and floodplain master plans are the main instruments for developing a sustainable policy for managing the effects of floods in urban areas. The management of urban floods in developing countries also requires the evaluation of socioeconomic problems related to land use and urban development. Most control can be achieved through legislation and its enforcement, public participation and capacity building.

Overall, addressing urban flooding requires a combination of effective infrastructure planning, sustainable land-use practices, public participation, and incentives to encourage proactive engagement from individuals and communities.

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