

# Blue-green infrastructure: a multifunctional alternative to watersheds with socio-environmental vulnerability

M. V. R. Gomes<sup>1\*</sup>, V. A. Rutigliani<sup>2</sup> & A. P. Veról<sup>1</sup>

<sup>1</sup>*Programa de Pós-Graduação em Arquitetura (PROARQ/UFRJ), Universidade Federal do Rio de Janeiro, Pedro Calmon Av., 500, Sala 433 - Cidade Universitária, Rio de Janeiro, Brazil, 21941-901.*

<sup>2</sup>*Faculdade de Arquitetura e Urbanismo da UFRJ (FAU-UFRJ), Universidade Federal do Rio de Janeiro, Pedro Calmon Av., 500, Bloco D, Térreo - Cidade Universitária, Rio de Janeiro, Brazil, 21941-901.*

\*Corresponding author email: [maria.gomes@fau.ufrj.br](mailto:maria.gomes@fau.ufrj.br)

## Highlights

- The use of BGI can improve the relationship between the urban space and the river.
- This work aims to offer a solution to floods in dense and consolidated watersheds using BGI.
- The obtained results showed the importance of incorporating BGI alternatives to flood control.

## Introduction

The uncontrolled urban growth process, especially combined with inadequate land-use planning and lack of social policies that ensure housing for the low-income populations has increased socioeconomic and environmental problems, influencing hydrological modifications and ecosystem losses. Moreover, considering the traditional flood control solutions, which are usually designed as a corrective intervention of local character (Rezende et al., 2019), urban floods has become a challenge to city managers, due to their damages on buildings, interruption of business and services, disruption of mobility, among other problems (Veról et al., 2020). However, a paradigm shift in river management is recognized, considering to leave single and traditional approaches, to a new debate on river restoration, including multifunctionality of urban spaces, ecosystem services and quality of life (Chou, 2016). In this sense, the blue-green infrastructure (BGI) concept is also considered as a shift from a monofunctional view, towards the recognition of multifunctional solutions that include natural green and blue elements, like lakes, parks and urban greenery; and man-made interventions, as permeable pavements, bioswales, retention basins, and constructed wetlands, for example (Ahmed et al., 2019). Therefore, BGI can enhance resilience by increasing the possibilities of infiltration and storage of water.

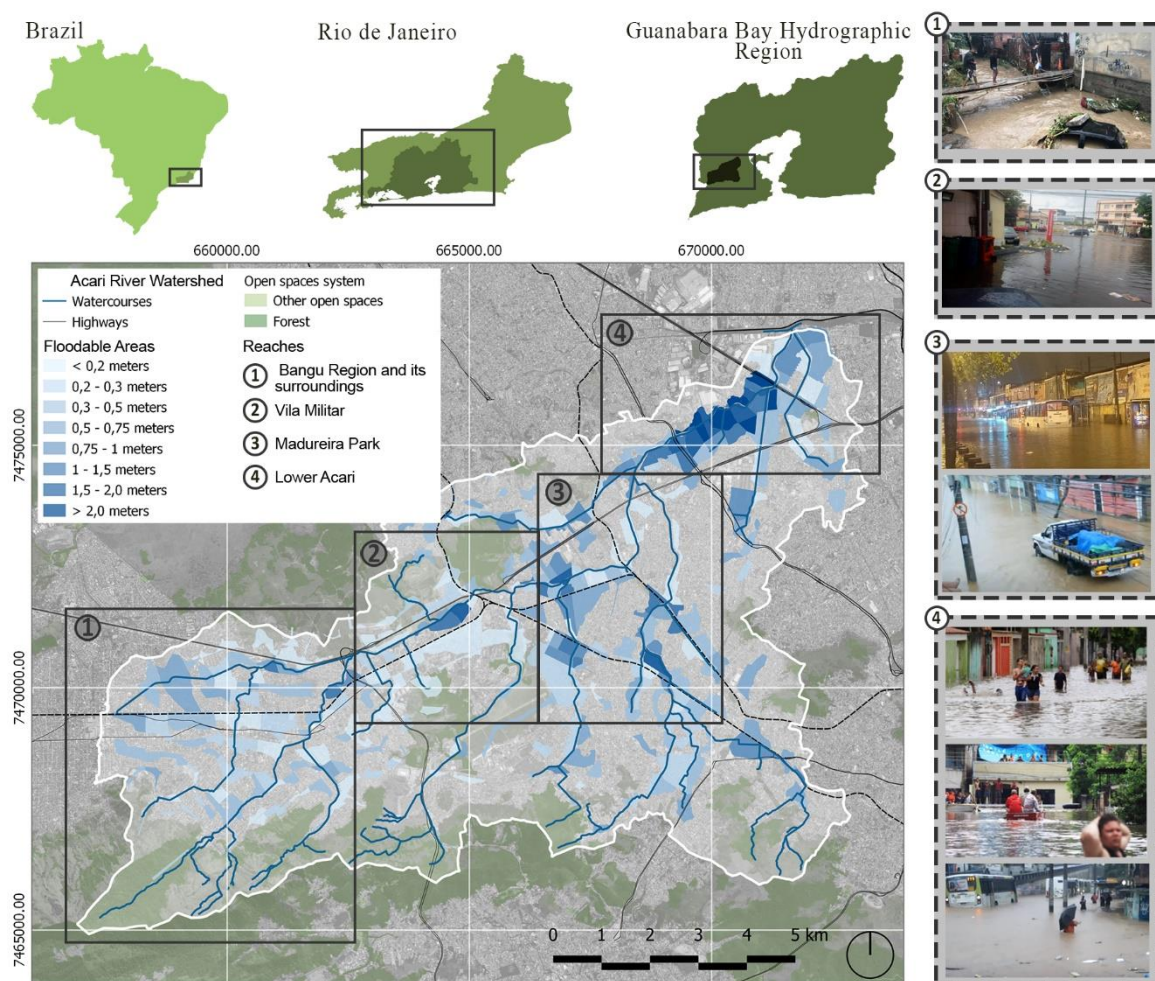
However, despite nature-based solutions have been widely discussed in the literature, hard engineering is still used as a main flood control strategy in developing countries such as Brazil, reflecting a lack of political motivation and public acceptance of these integrated approaches. As a consequence, socio-environmental vulnerabilities of the watersheds are increasingly aggravated, especially during flood events. This work aims to explore BGI as an alternative to conventional urban drainage projects, approaching its multifunctional character in flood control, environmental recovery and creation of recreational spaces in the Acari River Watershed, located in the city of Rio de Janeiro, Brazil.

## Methodology

The methodology of this work is divided in three steps: (1) literature review; (2) diagnosis of the case study; and (3) proposition of design guidelines. The first step focuses on a bibliographic review of BGI. In the second step, a detailed diagnosis of the selected watershed was carried out considering land use and occupation, topography, hydrology, the existence of open spaces and floodable areas. This analysis was supported by Geographic Information Systems (GIS) and by the study of Oliveira et al. (2018), who conducted a diagnosis of flooding areas using MODCEL as a hydrodynamic mathematical simulation tool in the Acari River Watershed. The third step proposes BGI guidelines as systemic solutions to mitigate floods in dense watersheds, improving the relationship between the urban space and the river. It is expected that these guidelines can be applied in similar regions, considering public participation.

## Results and discussion

The Acari River Watershed was selected because of its challenges related to stormwater management and social vulnerability. The diagnosis, supported by GIS mapping, showed a dense and consolidated watershed, with low predominance of urban green spaces, which correspond to environmental protection areas, parks, and private lands. The Acari River is formed by 12 watercourses, with their sources located at an environmental protection area at the watershed highest elevations. As the watershed gets plain, urban occupation modifies the natural watercourses, which is aggravated by the occupation of low-income populations with precarious sanitation conditions. The diagnosis led to the definition of four main reaches based on the similarity of the watershed patterns of occupation, which would enable to suggest design guidelines compatible with each situation. These reaches are: (1) Bangu Region and its surroundings; (2) Vila Militar; (3) Madureira Park; and (4) Lower Acari (Figure 1). Reach (1) presents small areas of environmental protection near the river sources, ensuring their protection. However, the flat areas of the watershed present a dense residential occupation without open spaces. Reach (2) is a region of traditionally military and institutional occupation with a relevant proportion of open spaces. Although this space is not available to the population due to its private nature, it guarantees a portion of permeable area, presenting fewer floodable areas. Reach (3) presents an important park called “Madureira Park”, which is the only open space infrastructure in a densely populated area. Reach (4) is located at the lowest and most critical point of the watershed, where the floodable areas reach more than 2 meters high, severely impacting the population in situations of socio-environmental vulnerability.



**Figure 1.** The Acari River Watershed – Rio de Janeiro, Brazil.

The literature review and the watershed diagnosis led to the indication of BGI solutions to compose a design alternative. Considering the division into four reaches, general guidelines were developed to be applied throughout the watershed, to develop the urban quality from source to mouth; as well as specific

proposals for each reach, contemplating its singularities. As a general strategy, a fluvial park acting as an urban green corridor is suggested, being responsible for enhancing resilience by increasing infiltration opportunities. The linearity of these green corridors has the potential to connect fragmented green areas, improve the river water quality, as well as the opportunity to offer recreational spaces near the river.

As specific strategies for Reach (1), once the river sources are protected by environmental protection areas, it is suggested to encourage the preservation of local native vegetation, followed by policies to control occupations on the riverbanks. For the residential zone, it is important to ensure a correct wastewater management, preserving the river water quality. For Reaches (2) and (3), which present open green spaces that can be incorporated into the fluvial park system, such as the Deodoro's public pool at Vila Militar (Reach 2), and the Madureira Park (Reach 3), it is suggested the revitalization and use of their landscape potential, to interconnect public facilities and enhance relationship between the river and the local residents. Finally, Reach 4 is highlighted as the most critical area and should be the focus of a more in-depth study. Initially, a retention pond is suggested to compose the larger available area, due to the possibility to retain stormwater during flood events and improve wastewater treatment from the irregular occupations. However, considering the existence of floodable areas, it is also necessary to consider, with the public participation, a relocation strategy for specific residents that are at risk. As general recommendations to control floods in dense urban areas, it is also suggested to improve permeability along the watershed through the adoption of rain gardens and bioswales. The building scale could also be improved by the adoption of permeable pavements or green roofs at public buildings, such as schools.

## Conclusions and future work

This study aimed to offer a multifunctional alternative to floods in dense and consolidated watersheds through the use of blue and green infrastructure. The Acari River Watershed, with dense residential occupation, few open spaces, and some important floodable areas, was selected as case study. BGI solutions were indicated as a multifunctional alternative to complement the existing drainage network, increasing reservation and infiltration opportunities. However, the condition of the low-income populations that live on the riverbanks is probably one of the most challenges of the present study, considering the need to reduce exposure to risks and guarantee sanitation services and adequate housing conditions. It is expected that the BGI guidelines presented in this study could be replicated and evaluated in similar regions, highlighting the importance of managing vulnerable watersheds. This work is part of an ongoing master thesis. The future step of this research intend to evaluate the effectiveness of BGI in reducing flood in the Acari River Watershed using a hydrodynamic model called MODCEL.

## Acknowledgements

This work was supported by the *Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro* (FAPERJ) [E-26/200.417/2021]; and by the *Programa Institucional de Bolsa de Iniciação Científica* from the Federal University of Rio de Janeiro (PIBIC-UFRJ) [Edital nº 169 CEG/CEPG 2020]. We also acknowledge the UNESCO Chair for Urban Drainage in Regions of Coastal Lowlands from the Federal University of Rio de Janeiro, to which this research is linked.

## References

- Ahmed S., Meenar, M., Alam, A. (2019). Designing a Blue-Green Infrastructure (BGI) Network: Toward Water-Sensitive Urban Growth Planning in Dhaka, Bangladesh. *Land*, 8(138), 1-21.
- Chou, R. (2016). Achieving Successful River Restoration in Dense Urban Areas: Lessons from Taiwan. *Sustainability*, 8(1159), 1-23.
- Oliveira, A. K. B.; Bigate, I. L., Machado, R. K., Sousa, M. M., Rezende, O. M., Magalhaes, P. C., Miguez, M. G. (2018). Drainage System and Flood Control as a Preliminary Structuring Axis for Urban Planning: Case Study of the Acari River Basin, in the Metropolitan Region of Rio de Janeiro. In: 13th Conference on Sustainable Development of Energy, Water and Environment Systems, Palermo, Italy.
- Rezende O. M., Franco, A. B. R. C., Oliveira, A. K. B., Jacob, A. C. P., Miguez, M. G. (2019). A framework to introduce urban flood resilience into the design of flood control alternatives. *Journal of Hydrology*, 576(2019), 478-493.
- Veról A. P., Lourenço, I. B., Fraga, J. P. R., Battemarco, B. P., Merlo, M. L., Magalhães, P. C., Miguez, M. G. (2020). River Restoration Integrated with Sustainable Urban Water Management for Resilient Cities. *Sustainability*, 12(4677), 1-36.