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Cartography of urban floods in the Canal do Mangue Basin – RJ: the new configuration post-macrodrainage works

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Cartografia das enchentes urbanas na bacia do Canal do Mangue – RJ: a nova configuração pós-obras de macrodrenagem

RESUMO

Objetivo - Identificar as mudanças na mancha de enchente urbana da Bacia do Canal do Mangue (BCM) após a realização de obras de macrodrenagem.

Metodologia - Foram aplicados questionários aos trabalhadores da região previamente afetada, utilizando dados fornecidos pela Prefeitura da Cidade do Rio de Janeiro para direcionar a amostragem.

Originalidade/relevância - O estudo aborda o impacto das obras de macrodrenagem finalizadas em 2019 na BCM, uma área historicamente afetada por enchentes urbanas. A pesquisa contribui para a compreensão da relação entre intervenções estruturais e a percepção das mudanças no impacto das enchentes.

Resultados - Os entrevistados reportaram melhorias nas características das enchentes, como a redução da altura da lâmina d'água, da recorrência e da extensão da área afetada. No entanto, 73% ainda relataram a existência de enchentes em frente aos seus locais de trabalho, principalmente em áreas de menor altitude.

Contribuições sociais e ambientais - O estudo destaca a necessidade de intervenções adicionais em áreas de menor altitude, promovendo um planejamento mais inclusivo para a mitigação de riscos ambientais e melhoria da qualidade de vida na BCM.

PALAVRAS-CHAVE: Enchente urbana. Percepção de risco. Bacia do Canal do Mangue.

Cartography of urban floods in the Canal do Mangue basin – RJ: the new configuration post-macrodrainage works

ABSTRACT

Objective – To identify changes in the urban floodplain of the Canal do Mangue Basin (BCM) following the completion of macro-drainage works.

Methodology – Questionnaires were administered to workers in the region previously affected, using data provided by the Municipality of Rio de Janeiro to guide the sampling process.

Originality/Relevance – The study examines the impact of macro-drainage works completed in 2019 in the BCM, an area historically affected by urban floods. The research contributes to understanding the relationship between structural interventions and perceptions of changes in flood impacts.

Results – Respondents reported improvements in flood characteristics, such as reduced water depth, frequency, and affected area extent. However, 73% still reported the occurrence of floods in front of their workplaces, particularly in lower-altitude areas.

Theoretical/Methodological Contributions – The study reinforces the importance of combining empirical data, such as questionnaires, with geospatial and hydrological analysis to evaluate the impacts of macro-drainage interventions. This approach provides a nuanced understanding of urban flood dynamics and the effectiveness of infrastructure projects.

Social and Environmental Contributions – The findings emphasize the need for additional interventions in low-elevation areas to address persistent flooding, highlighting the importance of inclusive urban planning. This can contribute to mitigating environmental risks and improving the quality of life for residents and workers in the CMB.

KEYWORDS: Urban flooding. Risk perception. Canal do Mangue Basin.

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Cartografía de las inundaciones urbanas en la cuenca del Canal do Mangue – RJ: la nueva configuración post-obras de macrodrenaje

RESUMEN

Objetivo – Identificar los cambios en la extensión de la inundación urbana de la Cuenca del Canal do Mangue (CCM) tras la finalización de las obras de macrodrenaje en 2019.

Metodología – Se realizaron cuestionarios a los trabajadores de la región previamente afectada, utilizando datos proporcionados por la Alcaldía de la Ciudad de Río de Janeiro para guiar el proceso de muestreo.

Originalidad/Relevancia – El estudio aborda el impacto de las obras de macrodrenaje completadas en 2019 en la CCM, una región históricamente afectada por inundaciones urbanas, agravadas por el proceso de ocupación. La investigación contribuye al entendimiento de la relación entre las intervenciones estructurales y la percepción de los cambios en los impactos de las inundaciones, especialmente en áreas densamente pobladas.

Resultados – Los encuestados reportaron mejoras en las características de las inundaciones, como la disminución de la altura del agua, la recurrencia y el área afectada. Sin embargo, el 73% de los encuestados aún informó la presencia de inundaciones frente a sus lugares de trabajo, persistiendo principalmente en áreas de menor altitud, consideradas más vulnerables según diversos estudios.

Contribuciones Teóricas/Metodológicas – El estudio destaca la relevancia de combinar métodos empíricos, como cuestionarios, con análisis geoespacial e hidrológico para evaluar los impactos de las intervenciones de macrodrenaje. Este enfoque ofrece una comprensión detallada de las dinámicas de las inundaciones urbanas y la efectividad de los proyectos de infraestructura.

Contribuciones Sociales y Ambientales – Los hallazgos enfatizan la necesidad de intervenciones adicionales en áreas de menor altitud para abordar la persistencia de las inundaciones. Esto subraya la importancia de una planificación urbana inclusiva para mitigar los riesgos ambientales y mejorar la calidad de vida de los habitantes y trabajadores de la CCM.

PALABRAS CLAVE: Inundación urbana. Percepción de riesgo. Cuenca del Canal do Mangue.

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GRAPHICAL ABSTRACT

Mapping Urban Floods in the Canal do Mangue Basin – RJ: The New Configuration After Macro-Drainage Works

Canal do Mangue Basin (CMB) - Rio de Janeiro

Landfilled Mangrove Area = Historical Floods
2012-2019: Macro-Drainage Works

Objective:

Evaluate changes in the pattern of urban floods in the study area.

Methodology:

Survey with 100 workers in the CMB flood zone in 2022.

Results:

73% of respondents witnessed floods.

Flood recurrence:

41% state that floods occur whenever it rains.

Maximum water depth:

38% up to 30 cm
03% above 1.5 m

Impact of the works:

50% noticed improvements.
22% did not notice improvements.

Identified improvements:

45% Reduction in water depth;
24% Decrease in recurrence;
14% Reduction in affected area.

Conclusions:

Workers' perception provides a more accurate view of the spatial reality of floods.

Flood mapping is essential for proposing mitigation and prevention measures based on the local population's lived experiences.

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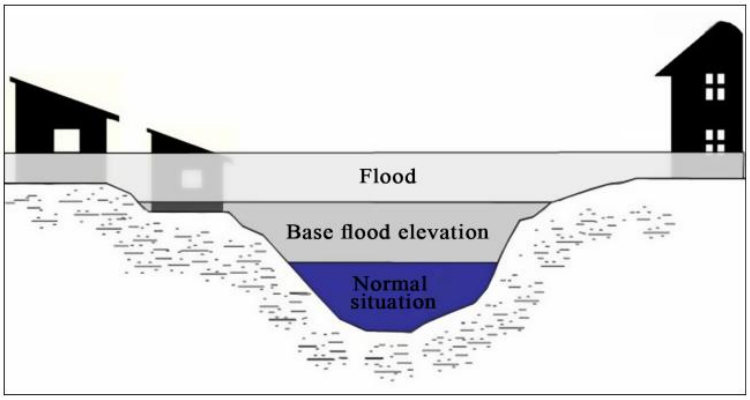
1 INTRODUCTION

Floods occur when rainfall intensity is high or its duration is prolonged, and the amount of water reaching the river simultaneously exceeds its drainage capacity. However, urban floods differ from the previous concept due to their complexity, which arises from modifications to the natural conditions of a basin, such as soil impermeabilization, morphological changes, or the straightening of channels.

> The hydrological system in urbanized areas exhibits specific characteristics compared to non-urbanized areas (regions with natural or cultivated vegetation formations), where human occupation is invariably less intense, and environmental changes tend to occur at less pronounced levels (BOTELHO and SILVA, 2012, p. 172).

In areas with intense urbanization, it is common to find the simultaneous occurrence of these different alterations. Therefore, it is not possible to differentiate the occurrence of the following processes: (I) flooding – represents the overflow of water from a watercourse, reaching the floodplain or wetland area; (II) floods – defined by the rise in water level within the drainage channel due to increased flow, reaching the channel's maximum capacity without overflowing (Figure 1); (III) waterlogging – temporary accumulation of water in specific locations due to deficiencies in the drainage system; and (IV) flash floods – concentrated surface runoff with high transport energy, which may or may not be associated with areas dominated by fluvial processes (Ministry of Cities/IPT, 2007).

Figure 1 - Schematic profile of the flood and based flooding elevation.



Source: Santos *et al*., 2020.

Historically, humans have occupied areas near rivers, which were sources of water for consumption and irrigation, as well as important means of transportation and communication until the early 20th century. In this way, urban floods generate enormous impacts for society, with significant economic losses and loss of life (SIQUEIRA *et al.*, 2019; TUCCI, 2007), due to their recurrence in densely populated areas.

In Brazil, according to the MapBiomas 2023 report, between 1985 and 2022 there was an increase in the urbanization of flood and inundation risk areas. The report points out that 11.5% of urbanized areas are susceptible to flooding. Another statistic highlights the

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occupation of riverbanks in Brazil, which increased from 61.6 thousand hectares in 1985 to 121 thousand hectares in 2020, with the highest occupation occurring in the southeastern states: São Paulo (12.94 thousand ha), Rio de Janeiro (7.28 thousand ha), and Minas Gerais (6.68 thousand ha) (MAPBIOMAS, 2024). Concurrently with the occupation or densification of areas near water bodies, there has been an increase in extreme weather events, leading to more frequent episodes of intense rainfall (MARENGO, 2023; SCHMOELLER *et al*, 2023; MARRAFON *et al*, 2020). The convergence of the occupation of flood-prone areas with the intensification of triggering events has resulted in an increase in high-risk areas.

The disaster risk management process has been developing since the end of the 20th century. However, despite the changes that have occurred, a constant over the last 50 years has been the initial need for risk identification. In this sense, numerous studies have been conducted to better understand urban floods, either through hydraulic modeling studies that aim to project flood zones based on different conditions (SOUZA *et al*, 2020; GOERL *et al*, 2017; MOMO *et al*, 2016; MAMEDE *et al*, 2015), or through cartography, which aims to evaluate the areas actually affected during recent events (MELOS *et al*, 2022; COSTA *et al*, 2018; AMANTE, 2006).

1.1 Study Area

The Canal do Mangue Basin (CMB – Figure 2), located in the municipality of Rio de Janeiro, is part of the set of basins of Guanabara Bay. It covers an area of 43.93 km², where the neighborhoods with the largest coverage area are Tijuca, Alto da Boa Vista, Grajaú, Rio Comprido, Vila Isabel, São Cristóvão, and Andaraí, which are densely populated.

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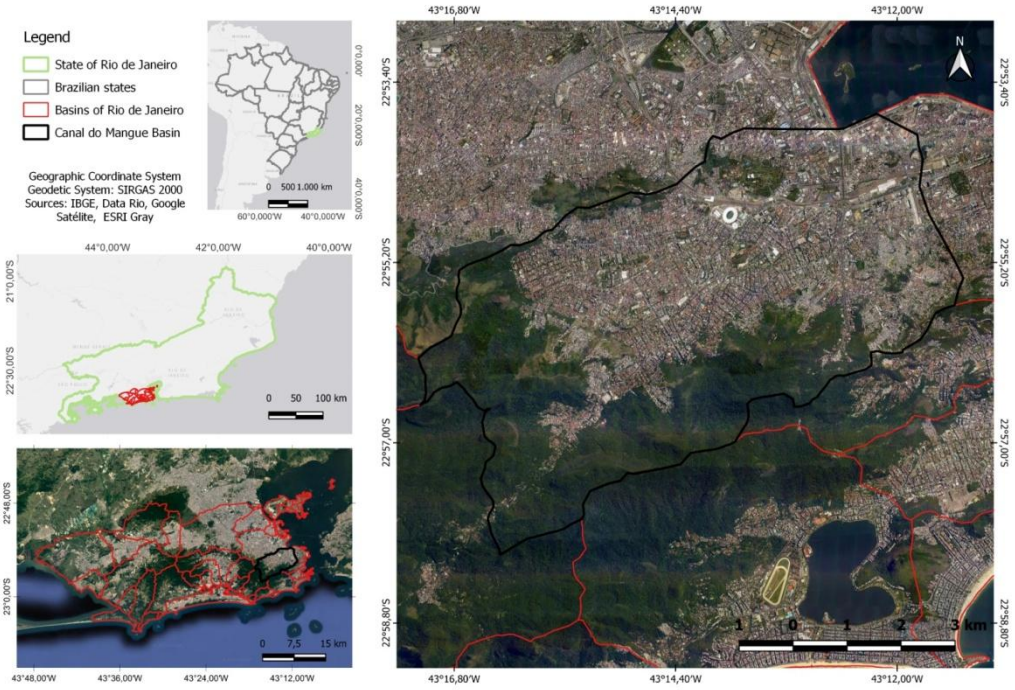
Figure 2 – Location of the Canal do Mangue Basin – Rio de Janeiro.



Source: Melos *et al.* (2023).

The main tributaries of the Mangue Canal are the Maracanã, Joana, Trapicheiro, Comprido, and Papa-Couve rivers, which have their sources in the Tijuca Massif or the Engenho Novo Range, and flow into the Mangue Canal (FUNDAÇÃO RIO ÁGUAS, 2009). These rivers originally had independent mouths in Guanabara Bay, but with the construction of the Mangue Canal, which began in 1857 and was completed in 1876, their mouths were diverted to this canal (FUNDAÇÃO COPPETEC, 2014). The construction of the canal was the first major sanitation project in the basin (FONSECA *et al*, 2024), driven by the need for the expansion of the city of Rio de Janeiro over the flooded area of Saco de São Diogo.

With the urbanization of the region, several anthropogenic interventions were carried out in the basin, including deforestation, soil impermeabilization, and changes to the drainage network with the canalization and straightening of rivers, among other actions, which intensified the flooding problem. As a result, the City of Rio de Janeiro, in partnership with the Federal Government, implemented the Greater Tijuca Flood Control Program (Programa de Controle de Enchentes da Grande Tijuca), with drainage works carried out by the Rio de Janeiro Municipality's Water Institute Foundation (Rio-Águas) (ROMAR, 2012). This project (Figure 3) was conceived as a comprehensive drainage plan for the Canal do Mangue Basin (CMB) and is being executed in phases.

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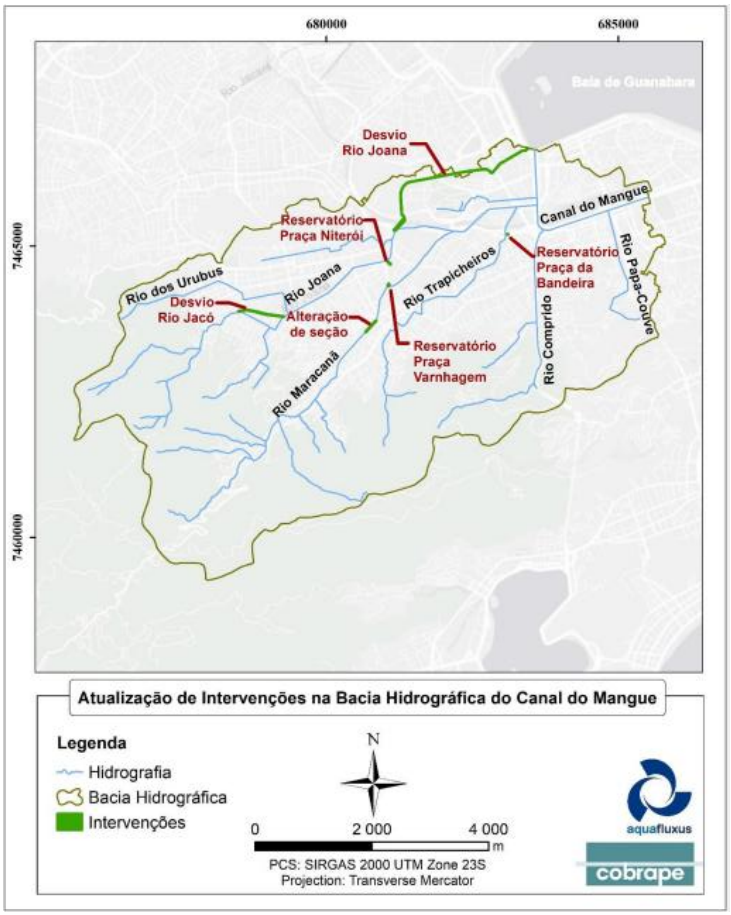
Figure 3 – Location of the main interventions in the macrodrenage system of the Canal do Mangue basin.



Source: Souza *et al*, 2020.

The first reservoir, inaugurated on December 29, 2013, at Praça da Bandeira, aims to reduce flooding during heavy rains in the region. With a capacity of 18 million liters, a depth of 20 meters, and a diameter of 35 meters, the reservoir receives all the water from the drainage network around the square, which is released in a controlled manner through three pumps, according to the network's capacity and the water level of the Trapicheiros River (CITY HALL OF RIO DE JANEIRO, 2013).

The three rainwater reservoirs at Praça Niterói were inaugurated on October 25, 2015. Built in an area of 4,568 square meters and with a depth equivalent to an eight-story building, they have a capacity to store 58 million liters of water. The stored water is released in a controlled manner into the watercourses, and the underground wells are interconnected to maintain the same water level (CITY HALL OF RIO DE JANEIRO, 2015).

On June 12, 2016, the Praça Varnhagen reservoir was inaugurated, which can store 43 million liters of water from the Maracanã River. Its structure includes a set of pumps to control the flow of water in and out, as well as an operational control room and control panel. The reservoir is 24 meters deep and occupies an area of 3,502 square meters (CITY HALL OF RIO DE JANEIRO, 2016).

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Finally, on April 25, 2019, the hydraulic tunnel connecting the Joana River to Guanabara Bay was established. With a total length of 3,412 meters, including 2,400 meters of tunnel and 1,012 meters of gallery, the canal starts beneath the intersection of Manoel de Abreu and Eurico Rabello Streets, allowing only 10% of the Joana River's original volume to flow (PEREZ, 2023).

2 OBJECTIVES

Since these works have contributed to changes in the urban flooding events within the watershed, the objectives of this study, therefore, are:

- To map urban flood areas after the installation of “large reservoirs” in the Canal do Mangue Basin;
- To compare the current urban flood areas with those mapped in previous studies before the installation of urban flood control structures;
- To assess the changes in the pattern of urban flooding in the study area.

3 METHODOLOGY

To achieve the objectives of this study, a literature review (books, articles, and theses) was first conducted, focusing mainly on urban flooding in the Canal do Mangue Basin (CMB). Subsequently, data collection and research took place: a) secondary data: Pereira Passos Institute; Water Institute Foundation of the Municipality of Rio de Janeiro, both linked to the City of Rio de Janeiro’s Municipality; b) primary data: development and application of a questionnaire targeted at the population working in the floodplain of the Canal do Mangue Basin, as identified by the Rio de Janeiro City Hallin 2011 (Figure 4).

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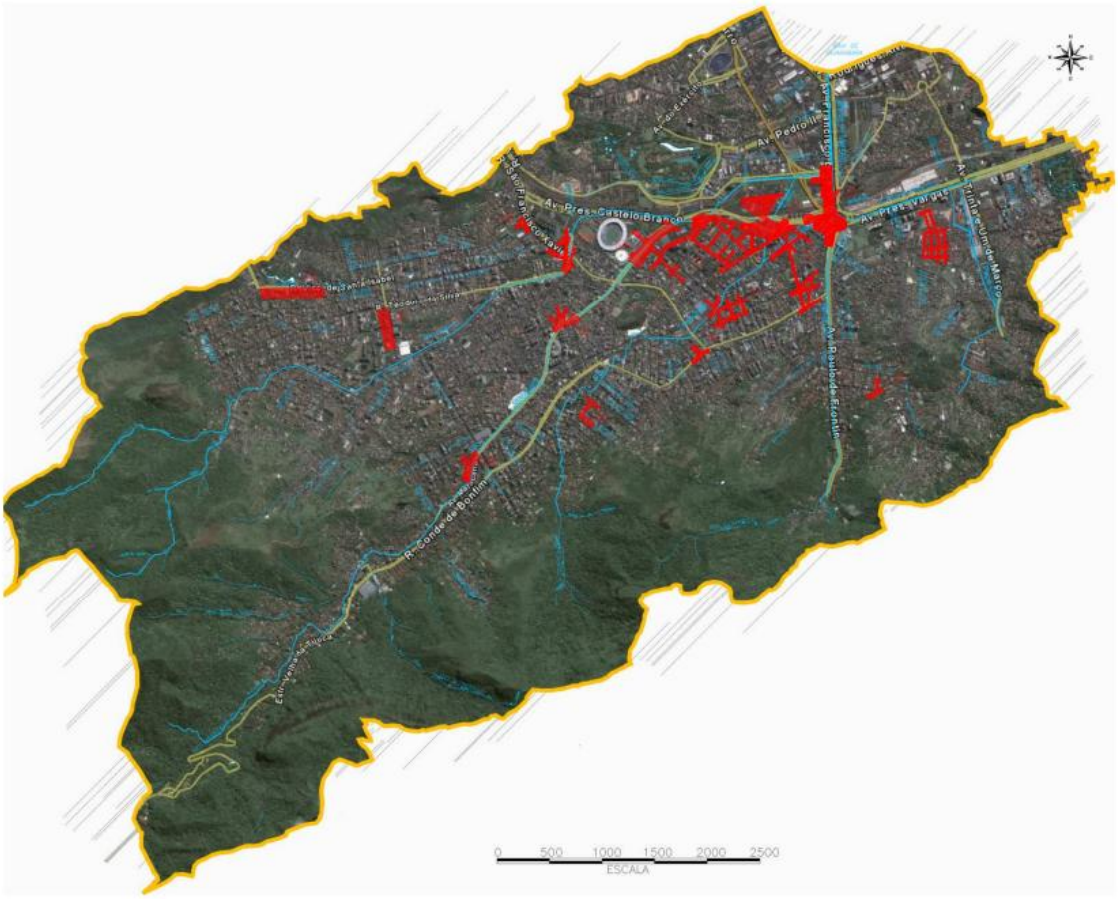
Figure 4 – Flood zones (represented in red) observed in the Canal do Mangue basin.



Source: City Hall of Rio de Janeiro (2011).

Next, the maps were created using ArcGIS 10.8 software, and the graphs were generated through Excel. Finally, the collected data was organized and analyzed, indicating the results obtained.

4 RESULTS AND DISCUSSION

A questionnaire was conducted with 100 workers from the CMB in 2022. The questionnaires were applied in commercial establishments.

Since the questions aimed to assess changes over time, the first question of the survey sought to characterize the interviewee based on the period they had worked at the interview location. The majority of respondents (41%) had worked at the interview location for 1 to 5 years, while 40% had worked there for more than 6 years. Only 18% had worked at the location for less than a year (Figure 5).

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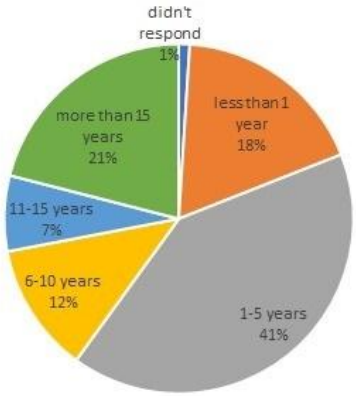
Figure 5 – Length of time respondents have worked at the visited location.



Source: The authors (2024).

Next, we asked whether they had ever witnessed an urban flood at that address, and 73% responded affirmatively. When restricted to the group with more than 10 years of experience in the CMB, the proportion of affirmative responses increased to 82%. In contrast, among the group with up to 5 years of work in the basin, the percentage of affirmative responses decreased to 68%. Despite the occurrence of adverse hydrological events (AHEs) monitored by Melos *et al*. (2023) and Vidal *et al*. (2024), their effects were perceived as less significant by workers with less time in the basin, especially those who arrived after the flood control works were nearly completed.

From a geographic evaluation of the responses, most of the points where urban flooding still occurs are located in the lower-lying areas of the basin (Figure 6), which aligns with the models conducted by Rezende (2018) and Souza *et al*. (2020).

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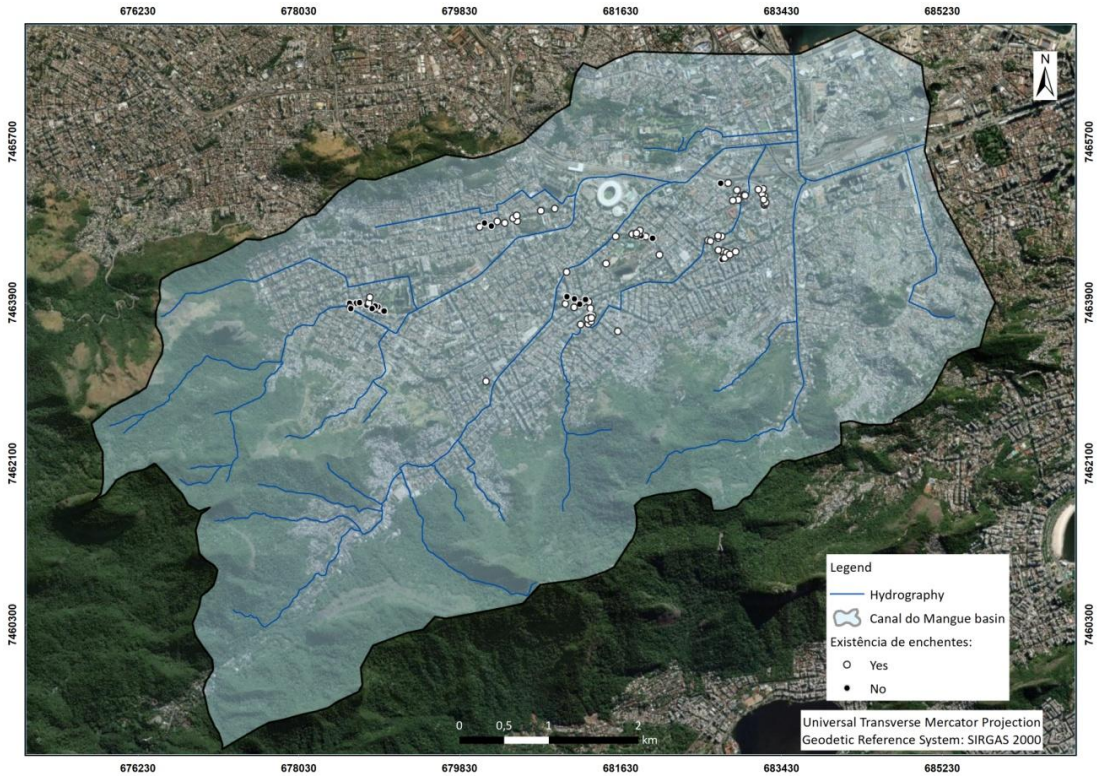
Figura 6 – Perception of urban flooding in the Canal do Mangue Basin, Rio de Janeiro (RJ).



Source: The authors (2024).

For the workers who reported having witnessed flooding or inundation, we asked about the frequency of these events. The majority (41%) responded that these events occur every time it rains. On the other hand, 26% were unable to evaluate the recurrence period of these events (Figure 7 – A). We also asked about the maximum water sheet height reached at the entrance of their establishment, with the majority (38%) reporting up to 30cm. Only 16% experienced heights between 81cm and 1.5m, and 3% experienced heights above 1.5m (Figure 7 – B). It is noteworthy that the values above 81cm were mostly concentrated in Rua do Matoso or its vicinity, the lowest area of the basin (Figure 8). This coincides with the models of Rezende (2018) and Souza *et al*. (2020), which show that these areas, located downstream from the natural course of the Maracanã River, present the highest flood depths, both currently and before the works carried out in the region. Similarly, it is observed that two of the three responses above 1.5m were related to Rua do Matoso, from workers who have been in the area for more than 15 years, covering the period prior to the partial completion of the macrodrainage works in 2013.

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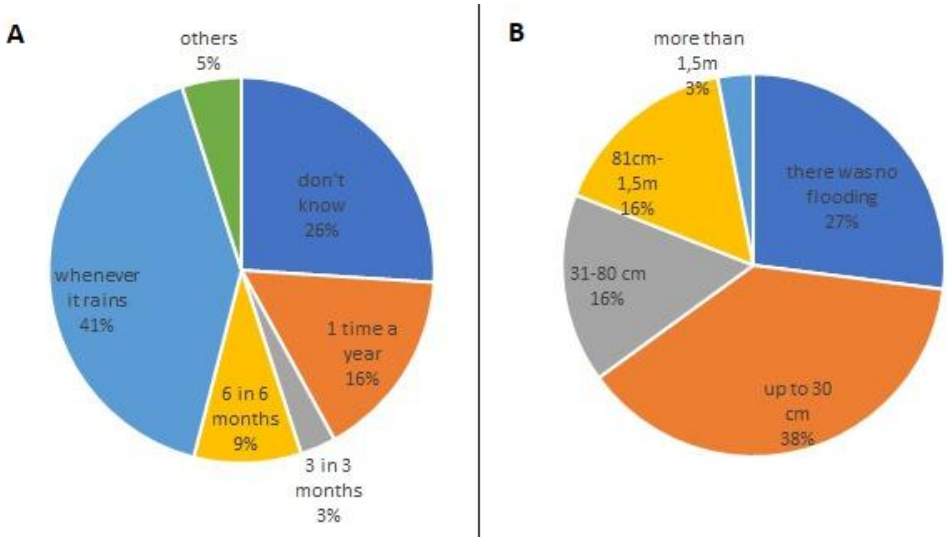
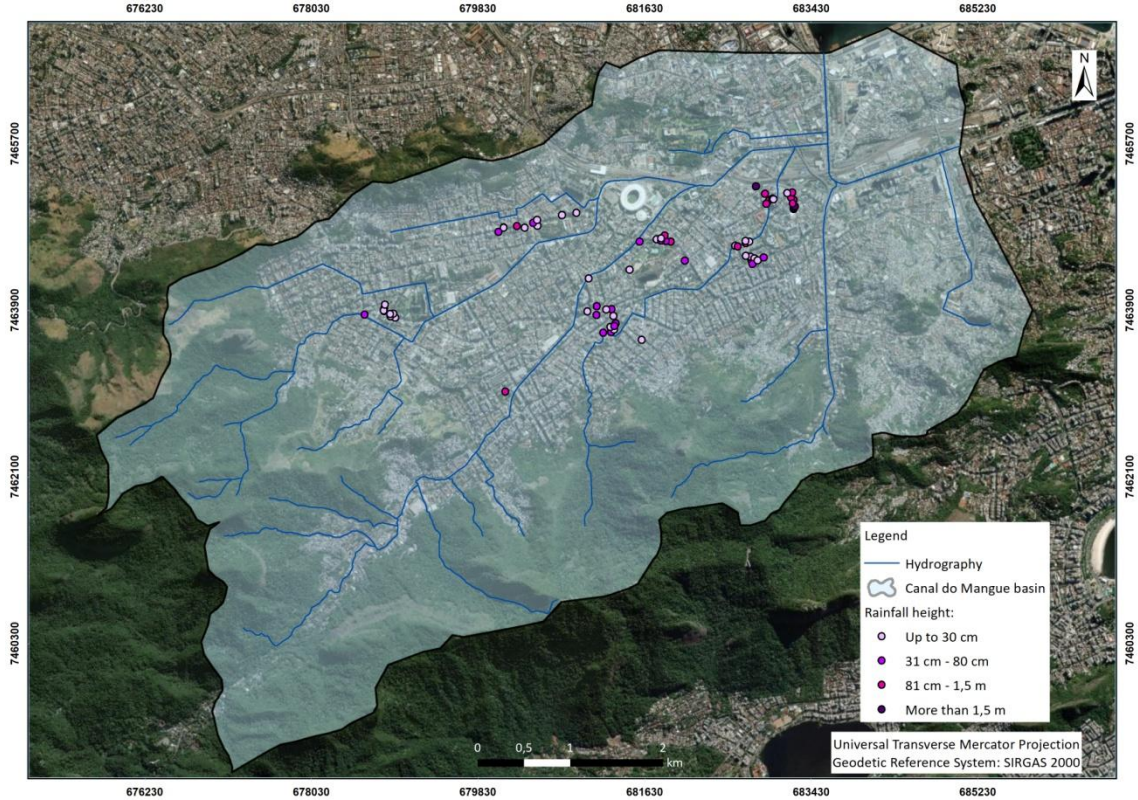
Figura 7 – (A) Flooding and inundation recurrence period; (B) Maximum water sheet height.



Source: The authors (2024).

Figure 8 – Maximum water sheet height in the Canal do Mangue Basin.



Source: The authors (2024).

Another point evaluated by the interviewees was the existence of drainage devices near the visited address. In 47% of the addresses, no drainage device was identified; in 39%, the presence of manholes was observed; in 12%, there were stormwater drains; in 1%, a curb was identified; and in 1%, a channel (Figure 9 – A). It is important to highlight that in some

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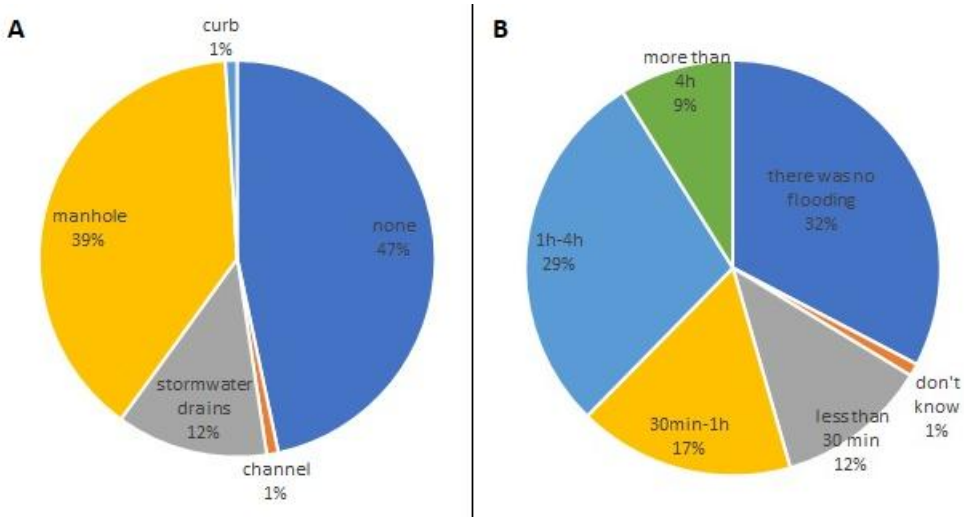
addresses, more than one type of device was found, totaling 105 responses in the sample. When asked about the time it takes for the water to drain, only 12% indicated that it takes less than 30 minutes. Seventeen percent reported between 30 minutes to 1 hour, 29% indicated between 1 and 4 hours, and 9% mentioned more than 4 hours (Figure 9 – B). In a cross-analysis with the drainage time of the water sheet, no relationship was found between the absence of devices and the longer or shorter drainage time. Spatially, the longest drainage times were concentrated in the lower part of the basin: around Praça Afonso Pena and near Praça da Bandeira, either at the beginning of Rua Mariz e Barros or Rua do Matoso (Figure 10).

Figura 9 – (A) Drainage device near the address; (B) Water sheet drainage time.



Source: The authors (2024).

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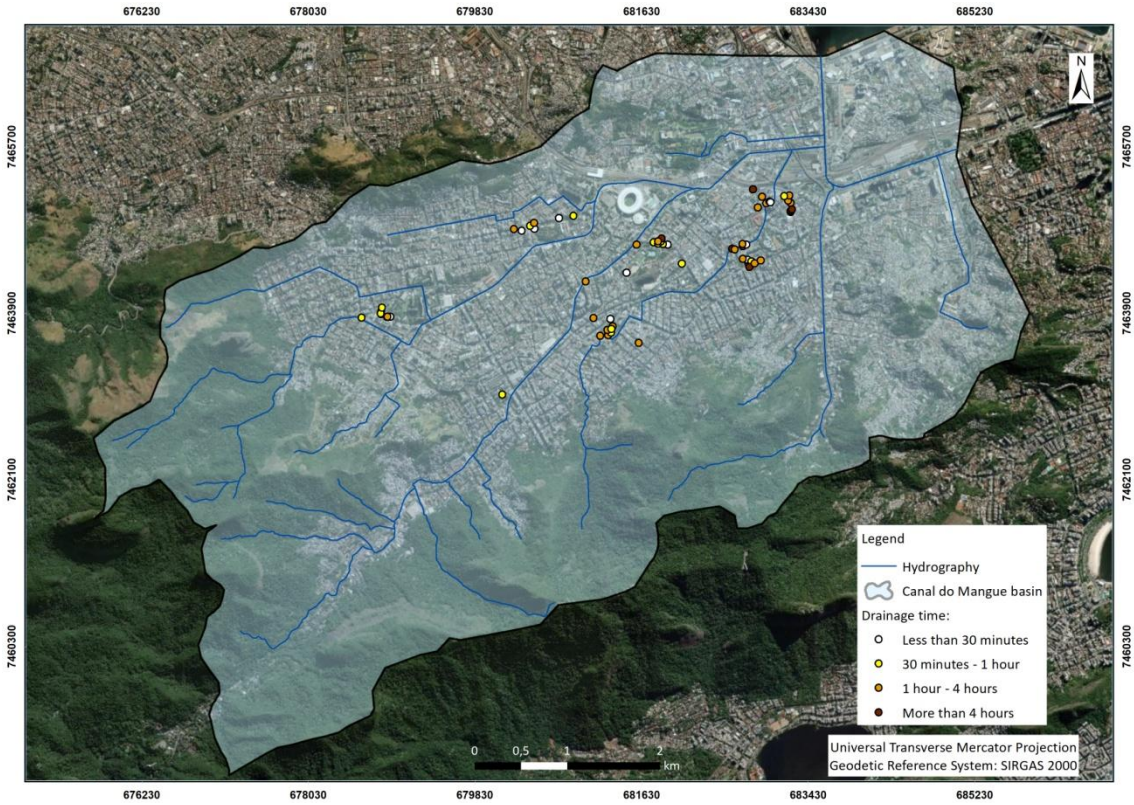
Figura 10 – Drainage time of the water sheet in the Canal do Mangue Basin.



Source: The authors (2024).

The interviewees were also asked if they were aware of the macro-drainage works in the region and if these works had brought positive impacts. Regarding the first question, 53% were aware of the works. Fifty percent believe that the "piscinões" (large reservoirs) have brought improvements to the Canal do Mangue Basin (CMB), while 28% did not know how to respond, and 22% believed that there had been no improvement. Among those who identified improvements, when asked what had improved, 45% could not specify, 18% mentioned a reduction in water sheet height, 24% noted a decrease in the recurrence of extreme hydrological events (EHA), and 14% pointed out a reduction in the affected area. This resulted in a total of 118 responses, as some respondents identified more than one type of improvement.

Corroborating the findings in the modeling by Souza *et al*. (2020), workers in the region observed that the main change in urban flooding near the Radial Oeste area was the reduction in the water sheet height. On the other hand, workers in the upper parts of the basin, where no improvements were identified in the models, reported reductions in recurrence, flooded areas, and/or water sheet height (Figure 11).

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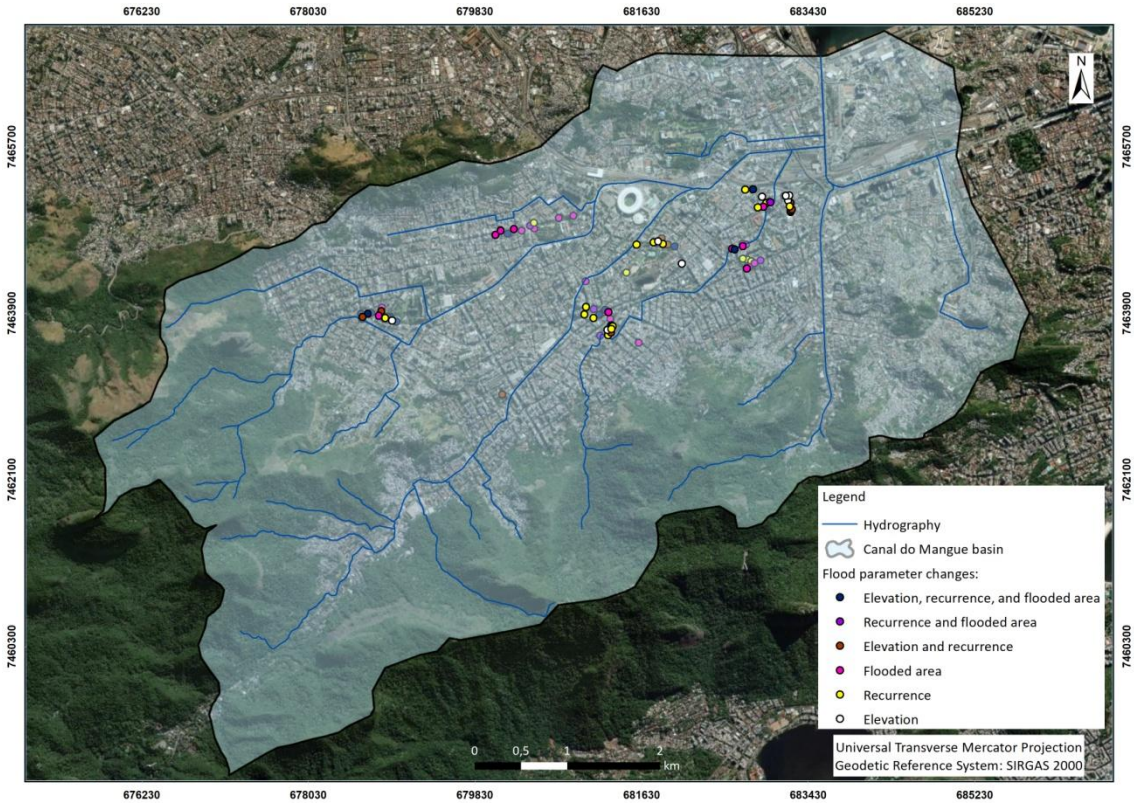
Figure 11 - Change in flood parameters in the Canal do Mangue Basin.



Source: The authors (2024).

Finally, we asked what people do to prevent flooding and how they would act if it occurred. Regarding the first question, we received 108 responses, with the majority indicating that they avoid throwing garbage in the street (82%). Six percent do not practice preventive measures, 6% engage in selective collection, 5% unclog drainage devices, and 1% do not know what to do. These data align with a previous study, where the population in the basin showed that the solution to the problem is the existence of in whichbins, street cleaning, and community awareness to prevent clogging of the drainage system (MELOS, 2023).

The measures already implemented are considered important to prevent urban flooding in the CMB by Souza *et al.* (2015), who state, however, that these actions do not exclude other measures by public authorities or private initiatives, such as the creation of detention basins or the installation of green roofs. Regarding the second question, most workers expect to stay at the location (43%) or move to a higher place (18%). However, 14% do not know what to do or take dangerous actions such as going home (2%) or unclogging drains (6%). In this context, self-protection becomes crucial—the ability of citizens to take actions for their own protection. Despite the recent establishment of the civil defense system in Brazil, it is recommended that local communities take action. Therefore, one should know what to do. In other words, "Civil Defense needs coordination, not centralization. Decentralization should be conceived and articulated with an increase in the individual and community self-protection capacity" (JONER *et al.*, 2021).

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5 CONCLUSION

The problem of urban flooding in the Canal do Mangue Basin (CMB) is historical, tracing back to the origins of its occupation. Since the region is vital for urban mobility in the city of Rio de Janeiro, large-scale macro-drainage works were carried out through the Flood Control Program of Grande Tijuca, which built rainwater reservoirs in the Bandeira, Niterói, and Varnhagen squares, as well as the hydraulic tunnel connecting the Joana River to Guanabara Bay.

For workers in establishments located within the CMB, based on the responses to the proposed questionnaire, the interventions in the region's urban drainage system have had a positive effect on urban flooding, which is concentrated to the north of the basin in areas of lower altitude and high imperviousness. Unfortunately, the works completed have not been able to completely eliminate the impacts of rainfall in the basin, but they have allowed for a reduction in the height, frequency, or area of the water layer.

The methodology used provides a better spatial understanding of the process through the perception of the people who work there, helping to validate or not the data obtained through modeling. Therefore, we recognize the importance of producing flood mapping work, which evaluates the lived reality in proposing mitigating and preventive measures related to the risk of urban flooding.

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CONTRIBUIÇÃO DE CADA AUTOR

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DECLARAÇÃO DE CONFLITOS DE INTERESSE

Nós, **Aline Riccioni de Melos e Tamiris Batista Diniz**, declaramos que o manuscrito intitulado "**Cartografia das enchentes urbanas na bacia do Canal do Mangue – RJ: a nova configuração pós-obras de macrodrenagem**"

1. **Vínculos Financeiros**: Não possui vínculos financeiros que possam influenciar os resultados ou interpretação do trabalho. Nenhuma instituição ou entidade financiadora esteve envolvida no desenvolvimento deste estudo.
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