Impacts of climate change and urban-related problems on flood events: a case from Rio de Janeiro, Brazil

L. M. C. Alves[1]*, A. K. Beleño de Oliveira[1], P. C. de Magalhães[1], O. M. Rezende[2] & M. G. Miguez[1]

[1]*Programa de Engenharia Civil (PEC), Instituto Alberto Luiz Coimbra de Pós-graduação e Pesquisa de Engenharia (COPPE), Universidade Federal do Rio de Janeiro (UFRJ), Av. Athos da Silveira Ramos, 149 - Centro de Tecnologia - Bloco B, Sala 101 - Ilha do Fundão, Rio de Janeiro, Brazil*

[2]*Escola Politécnica, Universidade Federal do Rio de Janeiro (UFRJ), Av. Athos da Silveira Ramos, 149, Centro de Tecnologia, Bloco I, Sala 206 - Ilha do Fundão, Rio de Janeiro, Brazil*

**Corresponding author email: lucas.alves@coc.ufrj.br*

Highlights

- The effects of climate change and urbanization on water levels were simulated.
- The watershed demonstrated varying responses from both factors depending on location.
- Generally, ineffective urban planning demonstrates larger increases in flood water levels.

Introduction

Urban floods constitute one of the most recurrent natural hazards (Wallemacq & House, 2018), accounting for 44% of all disasters between 2000 and 2019, with 1.65 billion people affected worldwide (CRED & UNDRR, 2020). From minor inundation events responsible to disrupt traffic and urban services to major floods capable of causing deaths and destroying livelihoods, these phenomena have affected humanity for centuries. Some examples demonstrate floods still severely impact populations. In 2011, the city of Brisbane, Australia, experienced a major flood event responsible for 24 deaths and economic losses above $4 billion Australian Dollars (van den Honert & McAneney, 2011). During the same year, a vast area of Thailand experienced high flood waters for up to 158 days, with damage estimations reaching $46.5 billion USD (The World Bank, 2012).

Several Brazilian cities also experience recurrent flood events. One of the most devastating natural disasters of the country also occurred in 2011. Extreme precipitation events caused major inundations and landslides responsible for 905 deaths and more than 300,000 people affected in the State of Rio de Janeiro (Sataloff et al., 2012). This major event has not been exceeded until the present day; however, smaller floods continue to negatively impact the State and the City of Rio de Janeiro.

According to IPCC (2014), floods will extremely likely increase in frequency and magnitude in the future due to climatic change. Several locations of the world are expected to experience more extreme precipitation events. Moreover, coastal regions face an additional consequence of climate change capable of exacerbating floods, which is sea level rise. Therefore, flood-related issues are also expected to aggravate (Kaykhosravi et al., 2020). This trend is further intensified because of urban challenges, which reduce the ability of the city to cope with inundation events. These challenges encompass uncontrolled urban expansion and insufficient maintenance of urban drainage systems, for instance.

The current study aims to identify the potential future consequences of flood events in a watershed in the city of Rio de Janeiro under different scenarios. The Acari River Watershed, with an area of 105 km^2 and outlet in the final kilometres of the Meriti River, which is a coastal basin, has experienced flood events for a long period. These events are magnified because of the high urban density of the area, the suppression of vegetation, and the low-income level of its inhabitants. Two of the top ten most populous *favelas* (slums) of the city are located within the basin, as well as the two most important and busy main roads of the State. Therefore, acknowledging the potential consequences of different future scenarios is a fundamental instrument for the development of efficient urban planning strategies for the area.

Methodology

Model and calibration

This study was developed using the Urban Flood Cell Model (MODCEL), a consolidated hydrologic-hydrodynamic model capable of simulating flood attributes, such as extent, velocity, and depth. MODCEL represents urban watersheds as flow cells which communicate with each other through well-established hydraulic laws, such as the Saint-Venant dynamic equation and others. The model also performs simple rainfall-runoff transformations within each cell to account for the design storm event. A detailed description of MODCEL can be found in Mascarenhas & Miguez (2002) and Miguez et al. (2017).

The model was calibrated using an extreme event from 11 December 2013. This event was chosen because of the availability of continuous data, and because of its devastating consequences, flooding several locations throughout the watershed.

Current Scenario

This baseline scenario considered the urban extent and density of the watershed in 2020 (Scenario 0). The rainfall event was derived through IDF curves established using data from three rain gauges of the area, considering a precipitation event of 25 years of Return Period, and a duration of 5 hours, which represents the time of concentration of the watershed.

Future Scenarios

This study considered five potential future scenarios in 2040. The first future scenario (Scenario 1) represented the effects of climate change. Considering projections from IPCC (2014), a 20% increase in the rainfall intensity of the current scenario along with a 0.65 centimetres per year of sea level rise were considered. The second future scenario (Scenario 2) was a reproduction of the first scenario without the consideration of sea level rise, aiming to identify the consequences of increases in precipitation individually.

The other scenarios did not consider climate change effects. The third future scenario (Scenario 3) demonstrates the effects of no maintenance of urban drainage systems. Assuming a Manning coefficient two times higher after 50 years from system's construction, the Manning coefficient for 2040 was calculated proportionally. The fourth future scenario (Scenario 4) represents unplanned urbanization in the watershed. Assuming a proportional increase of runoff coefficient and population, an increase of 14% was considered based on data from the Brazilian Institute of Geography and Statistics (IBGE, 2010). Finally, the fifth future scenario (Scenario 5) demonstrates the possible result of a combination of the third and fourth scenarios.

Results and discussion

The results, obtained through mathematical simulation, are shown in Figure 1 for the main stretch of the Acari River. Each line of the graph represents the difference between the water level of a future scenario and Scenario 0. Three sharp increases are noticeable. Water level increases at around 13,380 metres and between 8,000 and 10,000 metres from river outlet are due to the contribution of water volumes from three major tributaries of the Acari River, which are the Tingui, Arroio dos Afonsos and Piraraquara/Marangá Rivers. Their sub-basins are densely occupied, resulting in increased contributions of water volumes under all scenarios. Lastly, the sharp increase noticed at around 1,300 metres is a result of water flow restrictions due to the presence of a bridge, which already increases water levels high enough to cause flooding problems today.

The results demonstrate no significant differences between Scenarios 1 and 2. Minor differences are perceptible in the downstream region of the watershed; however, our results indicate that increases in precipitation would generate greater increases in water levels along the main river, even though the studied watershed discharges to the final stretch of a coastal basin.

Though Scenario 3 demonstrates the sharp increases previously discussed, it indicates decreases in some regions. This is a consequence of the lack of maintenance of drainage systems considered for the entire basin. Therefore, tributaries of the Acari River would experience increases in water levels and water flows arrive dampened in the main river. Scenario 4 demonstrates increases along the entire stretch of the Acari River;

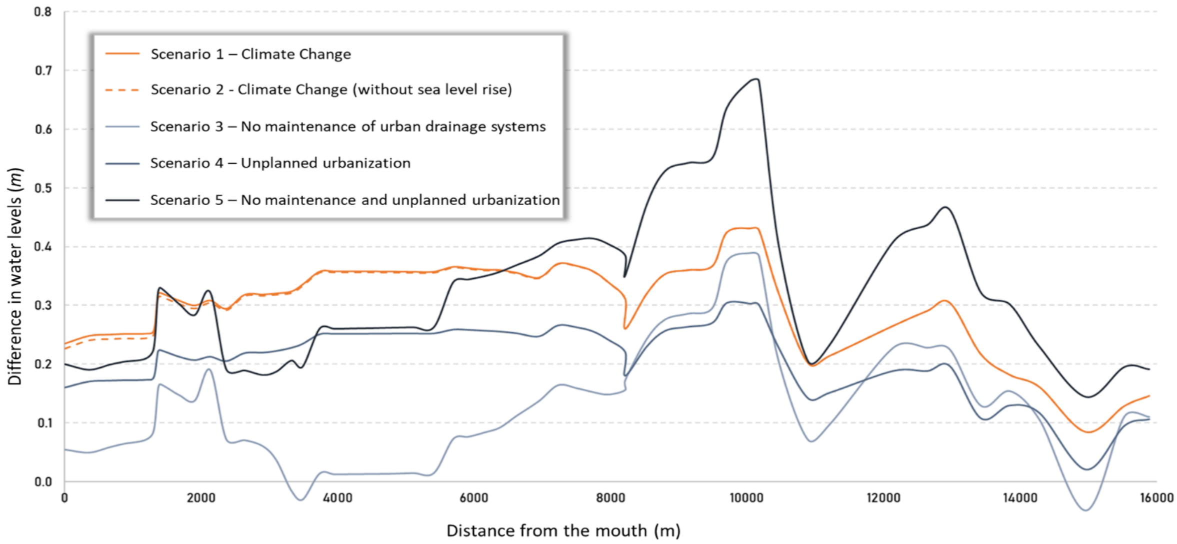

Figure 1. Comparison between the difference of water levels of different scenarios and the current scenario indicated in different stretches of the Acari River.

however, smaller increases are noticed upstream, where vegetated areas are still present. Scenario 5 shows an opposite behaviour, with increased differences in water levels upstream. This scenario indicates greater differences in most of the main river; however, climate change consequences overcome scenario 5 in the downstream region. According to our results, whilst climate change demonstrates more evenly distributed changes along the basin, scenario 5 indicates greater increases in already densely occupied areas, exacerbating current flood issues.

Conclusions and future work

This study aimed to analyse potential increases of flood related issues in the Acari River Basin, Rio de Janeiro, Brazil. Factors such as the increase of rainfall intensity and sea level rise, as consequences of climate change, and the lack of maintenance of drainage systems and uncontrolled urbanization, as consequences of inefficient urban planning, were considered. The findings demonstrate distinct effects of the scenarios proposed. Climate change exhibits increased influence downstream of the studied basin, whilst ineffective urban planning outcomes were significantly higher upstream. These findings suggest decision makers should prepare to face increasing challenges regarding flood related problems in the basin. Recognizing the potential scenarios of flood intensification is a fundamental instrument to aid the development of the best solutions, which is the proposed trajectory for the continuation of this project. Future works are expected to identify the best strategies to reduce flood water levels, considering the latest findings of the research community, which highlight the importance of integrating the city to the natural hydrological cycle.

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