


 <https://doi.org/10.71573/sj8z3g42>

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Evaluating Green Roof Retrofitting as a Stormwater Management Strategy in a Brazilian Urban Watershed

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Abstract

Urban flooding, driven by climate change and the expansion of effective impervious areas (EIA), poses growing challenges for sustainable urban development. Among nature-based solutions, green roofs (GRs) have gained attention for their potential to reduce surface runoff, promote infiltration, and restore aspects of the urban hydrological cycle. However, in Brazil, the adoption of GRs remains limited due to regulatory gaps and a lack of basin-scale impact studies. This research investigates the hydrological effects of GR retrofitting in a representative urban watershed in São José dos Campos, Brazil, through scenario-based modeling using the CAbc hydrological software. Scenarios were developed based on local policy frameworks, simulating varying degrees of GR implementation. The results suggest that GRs can enhance stormwater management by reducing runoff and delaying peak flows, especially under frequent, moderate rainfall events. Nonetheless, their performance tends to diminish during high-intensity storms, indicating the need for integration with other drainage strategies. The study highlights the value of GRs as part of a broader sustainable urban drainage system and supports the development of policies that incentivize their use to improve resilience in rapidly urbanizing regions.

Highlights

- Green roof retrofitting improved runoff management in a Brazilian urban watershed.
- Hydrological performance showed strong correlation with reduced impervious area.
- Results support local policy design for sustainable stormwater management.

Introduction

Urban flooding is an increasingly pressing issue, especially in densely built environments where impervious surfaces hinder the natural movement and absorption of water. This problem is further aggravated by climate change, which contributes to more frequent and intense rainfall events. Among the various impervious surfaces in urban areas, rooftops constitute a significant proportion, highlighting the potential of green roof (GR) retrofitting as an effective strategy for mitigating urban flood risks. By promoting infiltration and evapotranspiration, GRs improve stormwater retention and

delay runoff, thereby contributing to the restoration of the urban hydrological cycle (Gobatti and Leite, 2023).

An important concept in this context is the Effective Impervious Area (EIA), which refers to the portion of impervious surfaces directly connected to the stormwater drainage network and thus actively contributing to runoff generation (Palla and Gnecco, 2015). Although international experience has shown that public policies and incentives can successfully drive GR adoption, implementation in Brazil remains limited due to a lack of regulatory support and public engagement (Liberalesso *et al.*, 2020). Furthermore, few national studies have assessed the hydrological impacts of GRs at the watershed scale. This study aims to fill that gap by simulating GR retrofitting scenarios in the Senhorinha Creek watershed, located in São José dos Campos, São Paulo, under varying rainfall conditions. The findings reveal substantial reductions in peak flow and runoff volume as EIA decreases, underscoring the potential of GRs to support sustainable urban drainage and guide urban planning and policy development in Brazil.

Methodology

The analysis focused on the Senhorinha Creek watershed (9.26 km²), where land use includes residential areas (40.4%), roads (22.7%), green spaces (17.9%), commercial and service areas (6.4%), and other uses (7.8%). Hydrological modeling was conducted using CAbc software, dividing the watershed into three sub-basins (Amorim *et al.*, 2022). Model inputs included area, slope, curve number (CN), and imperviousness metrics. Calibration and validation used eight monitored rainfall events and yielded strong model performance. A GR module was calibrated using runoff data from 16 rainfall events over two years, with a CN of 89 and a time of concentration of 11.7 minutes.

Four retrofitting scenarios were tested: (1) Base (no GR), (2) Mandatory (10% GR on all applicable properties), (3) Incentivized (80% GR in residential areas, 10% in others), and (4) Ideal (80% GR across all areas). These were aligned with existing municipal legislation. Simulations assessed hydrological performance under 2-, 5-, and 10-year return period rainfalls, focusing on peak flow attenuation, delay, and runoff volume reduction.

Results and discussion

The results suggest that more extensive implementation of GRs can yield significant hydrological improvements, including reductions in surface runoff and delays in peak flow timing. The magnitude of these benefits was found to correlate strongly with the reduction in EIA, emphasizing the role of strategic roof coverage in enhancing performance. However, the analysis also indicates that the effectiveness of GRs may diminish under extreme precipitation events, highlighting the importance of integrated infrastructure solutions.

Conclusions and future work

GRs show potential to improve urban hydrological response under typical rainfall conditions. Their broader implementation may benefit from policy incentives and integration with other drainage strategies. Further research is needed to assess long-term impacts, water quality effects, and performance in combined green infrastructure systems.

Acknowledgement

The authors gratefully acknowledge the research support provided by the Hydraulic Technological Center Foundation (FCTH) and the city of Sao Jose dos Campos.

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