Linear Parks as a strategy to protect fluvial areas and control urban flooding

Les Parcs Linéaires comme stratégie de protection des zones fluviales et de contrôle des inondations urbaines

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RÉSUMÉ

Les bassins versants urbains, en particulier dans les zones côtières, sont de plus en plus exposés à des inondations accrues en raison de la variabilité climatique et de l'expansion des surfaces imperméables. Cette étude évalue les effets hydrologiques de la mise en place de parcs linéaires comme stratégie fondée sur la nature pour atténuer les inondations urbaines dans le bassin versant du Córrego Grande, dans le sud du Brésil. Un modèle hydrologique–hydrodynamique couplé 1D–2D a été développé dans PCSWMM, calibré et validé à partir d'événements observés, et a présenté une performance satisfaisante (R > 0,70, RMSE < 1,3, NSE > 0,3, ISE ≤ 6). Quatre scénarios ont été simulés, variant selon la largeur des corridors riverains végétalisés. Les parcs linéaires ont entraîné une réduction modérée du volume total de ruissellement, mais ont fortement atténué les débits de pointe, avec des réductions de 19,7 à 22,7 % pour le premier pic et de 11,4 à 13,8 % pour le second. De manière significative, le bassin versant est devenu capable de répondre à un événement pluvial de période de retour de 100 ans avec un comportement hydrologique comparable à celui d'un événement de 50 ans dans la condition pré-intervention, démontrant une augmentation notable de sa résilience. Dans l'ensemble, ces résultats montrent que les parcs linéaires améliorent la performance hydrologique et constituent une stratégie fondée sur la nature transférable pour une gestion durable des eaux urbaines et l'adaptation au changement climatique.

ABSTRACT

Urban watersheds, particularly in coastal areas, are increasingly vulnerable to intensified flooding driven by climate variability and the expansion of impervious surfaces. This study assesses the hydrological impacts of implementing linear parks as a nature-based approach to mitigating urban flooding in the Córrego Grande watershed, southern Brazil. A coupled 1D–2D hydrological–hydrodynamic model was developed in PCSWMM, calibrated and validated using observed events, and achieved satisfactory performance (R > 0.70, RMSE < 1.3, NSE > 0.3, ISE ≤ 6). Four scenarios were simulated, varying in the width of vegetated riparian corridors. The linear parks produced modest reductions in total runoff volume but substantially attenuated peak flows, with reductions of 19.7 to 22.7 per cent in the first peak and 11.4 to 13.8 per cent in the second. Importantly, the watershed became capable of responding to a 100-year rainfall event with hydrological behaviour comparable to that of a 50-year event in the pre-intervention condition, demonstrating a marked increase in resilience. Overall, the findings show that linear parks enhance hydrological performance and constitute a transferable nature-based strategy for sustainable urban water management and climate adaptation.

KEYWORDS

Climate change impacts, flooding management, Linear Parks, resilient cities, urban basins

1 INTRODUCTION

In recent years, society has become increasingly aware of climate-related challenges, particularly the intensification of extreme events such as droughts and flooding resulting from changes in the hydrological cycle (Granata and Di Nunno 2025). Intensified precipitation, combined with accelerated urbanisation, has imposed significant challenges on urban planning, leading to higher flooding frequency, greater pressures on drainage infrastructure, and substantial economic and social impacts (Li et al. 2022). Although extreme events are inevitable, their evolution into disasters can be mitigated through effective planning and resilient urban water management strategies.

Nature-based solutions (NbS) have emerged as a valuable class of green infrastructure for sustainable urban water management (Ibrahim et al. 2020). By expanding and reconnecting green spaces, NbS enhance the capacity of cities to mitigate rising temperatures, reduce flooding risks, and improve adaptation to climate change (Kabisch et al. 2016). Among these solutions, linear parks represent an important strategy for flooding attenuation. Implemented along watercourses, they preserve fluvial corridors, allow floodplain expansion during high-flow periods, and provide recreational, ecological, and educational benefits during dry periods (González et al. 2023).

Despite the wide adoption of green infrastructure in developed countries such as the United States, Canada, Australia, and France (Fletcher et al. 2014), many developing countries still face significant knowledge gaps regarding feasibility, performance, and integration into local urban planning frameworks, despite notable advances in countries such as China. Designing effective urban water management strategies requires understanding both the environmental characteristics of urban watersheds and the interactions among climatic, hydrological, and socio-environmental factors (Perrone et al. 2020). Although the number of studies on NbS has grown substantially in recent years, empirical and modelling-based assessments of linear parks as macro-drainage infrastructure for urban flooding control remain limited. In this context, the present study assesses the hydrological impacts of implementing linear parks as a nature-based approach to mitigating urban flooding in a coastal urban watershed.

2 METHODS

A simplified drainage system was developed for the Córrego Grande watershed. Precipitation and streamflow data were monitored at 5-minute intervals between September 2017 and January 2018, along with temperature data for evapotranspiration estimation. Field surveys were conducted to verify and adjust the channelled hydrography, and six cross-sections of the main river channel were incorporated into the model. Junctions were placed at confluences and at channel section transitions. The modelled network consisted of 11 junctions and one outlet, and 15 sub-basins. For each contribution sub-basin, the following parameters were defined: area, basin width, slope, Manning's roughness coefficient (n), depression storage for pervious and impervious surfaces, and Curve Number (CN). Hydrological and hydraulic interactions were simulated using PCSWMM version 7.7.3895.

The calibration and validation process comprised three main steps: identification of the most sensitive parameters and definition of their uncertainty ranges; sensitivity analysis and manual parameter adjustment; and model validation. Model performance was evaluated using the Pearson correlation coefficient (R), Nash–Sutcliffe Efficiency (NSE), Integral of the Squared Error (ISE), and Root Mean Square Error (RMSE). After calibration, the 1D model was coupled with the 2D domain for flood surface analysis. The 2D domain included adjustments of surface roughness and infiltration parameters to improve flood representation.

To represent the presence of Linear Parks (LP) in the watershed, simulation scenarios were developed based on current environmental legislation and resilient urban planning guidelines. The geometric configuration of the parks was adapted from a typical cross-section, consisting of a central channel, vegetated riparian strip, and 3:1 side slopes, which promote diffuse drainage and attenuation of surface runoff. Linear parks were incorporated into the model using Low Impact Development (LID) units of the vegetated swale type, distributed continuously along both banks of the river. Four scenarios were simulated, namely: (i) absence of a linear park (pre-intervention condition); (ii) existing linear park; (iii) linear park with 30 m on each bank; and (iv) linear park with 50 m on each bank, as shown in Figure 1a. For all scenarios, a depth of 1 m, Manning's roughness 0.25, and vegetation fraction 0.1 were adopted, representing urban parks with managed herbaceous vegetation and sparse structures. Initial moisture was set at 50%, considering shallow groundwater, hydromorphic soils, and proximity to the river. Critical rainfall events with return periods (T) of 25, 50, and 100 years were used to assess the effects of increasing park width on surface runoff reduction and peak flow attenuation.

3 RESULTS

The model showed satisfactory performance, with R > 0.70, RMSE < 1.3, NSE > 0.3, and ISE ≤ 6, confirming its reliability in representing rainfall–runoff processes in the Córrego Grande watershed. The simulated hydrographs revealed a characteristic multi-peak behaviour, a phenomenon widely documented in international literature, with reports from the United Kingdom, Japan, France, Luxembourg, Germany, Austria, and the United States. This behaviour results from the combination of rapid and delayed hydrological responses associated with different runoff generation mechanisms. Figure 1b illustrates the multi-peak pattern, highlighting the temporal lag and differences in magnitude between successive peaks.

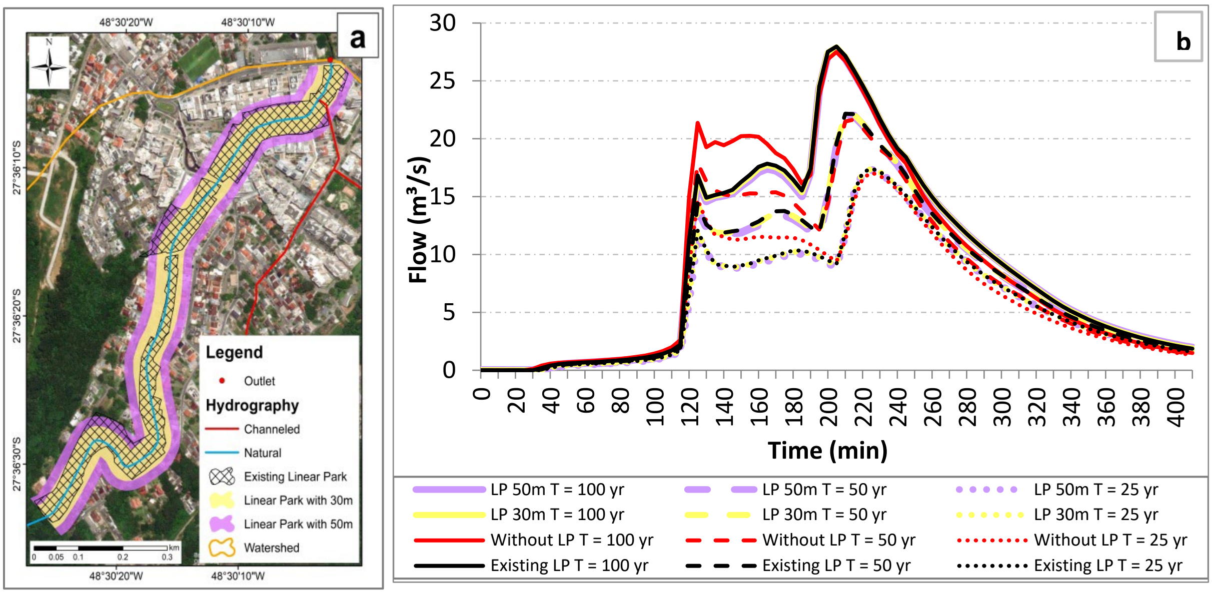

Figure 1 (a) Simulated linear park (LP) scenarios. (b) Multi-peak hydrological response of the Córrego Grande watershed.

The scenario simulations indicated that the presence of linear parks produced modest reductions in total runoff volume, with an average decrease of 2.05 per cent in the current scenario (existing LP) when compared with the condition without a linear park. Although volumetric effects were limited, the vegetated corridors played a substantial role in the attenuation of flood peaks. The results showed a consistent reduction in the first peak discharge (19.7 to 22.7 per cent) and a moderate reduction in the second peak (11.4 to 13.8 per cent), along with a slight increase in the basin concentration time. The third peak exhibited a small increase (1.2 to 2.0 per cent) in all scenarios, possibly associated with enhanced delayed flow resulting from higher infiltration rates within the vegetated areas, although this hypothesis requires further investigation.

Overall, the presence of linear parks significantly increased the hydrological resilience of the basin. Irrespective of the width adopted, the sub-basin became capable of withstanding a 100-year return period event with hydrological impacts equivalent to those of a 50-year event in the scenario without the park. The simulated flooding extent maps corroborate these findings, revealing a reduction in both the area and depth of flood, particularly in the 30-metre and 50-metre scenarios. Figure 2 presents the comparative flood maps for the different configurations, highlighting the spatial influence of the vegetated margins on flooding mitigation.

4 CONCLUSION

The findings demonstrate that linear parks constitute an effective nature-based strategy for mitigating urban flooding when integrated into the natural drainage system of the watershed. Despite modest reductions in total runoff volume, the vegetated corridors substantially attenuated the first and second flood peaks and increased the hydrological resilience of the Córrego Grande watershed. The watershed became capable of responding to a 100-year rainfall event with behaviour comparable to that of a 50-year event in the scenario without a park, underscoring the hydraulic benefits of preserving and widening riparian green margins.

The results also highlight limitations that warrant further investigation. The presence of multi-peak hydrograph responses indicates complex interactions between surface and subsurface flows that require more detailed monitoring at multiple locations within the watershed. In addition, the simplified representation of the built environment and the computational constraints associated with high-resolution two-dimensional meshes point to opportunities for future improvements in model accuracy. Overall, the study provides evidence that linear parks can meaningfully contribute to urban flood mitigation and offers a transferable modelling framework to support their incorporation into sustainable urban water management and climate adaptation strategies.

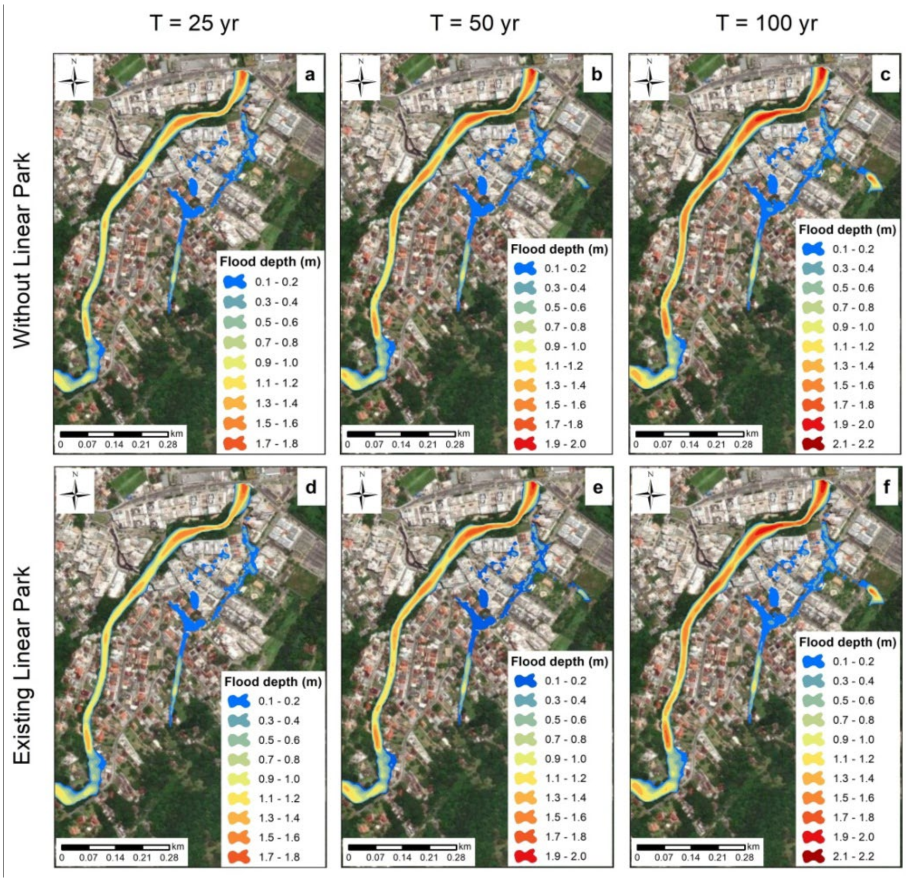

Figure 2 Comparative flood maps for the scenarios with and without a linear park.

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