A Comparative Study of Strategies for Modelling Current and Future Heavy Precipitation Effects Using Green Infrastructure

Juliana Reu Junqueira[1*], Silvia Serrao-Neumann[1,2], Iain White[1]

1 Environmental Planning Programme, School of Social Sciences, University of Waikato, Hamilton, New Zealand

2 Cities Research Institute, Griffith University, Brisbane, Australia

**Corresponding author email: julianareujunqueira@gmail.com*

Highlights

- We review models that assess the ability of green infrastructure to manage extreme rainfall
- Models rarely incorporate future climate change and development pressures
- Models link poorly to planning, and reflect data availability more than user's needs

Introduction

Urban areas need to find effective ways to mitigate the effects of, and adapt to, climate change, including floods resulting from extreme rainfall. Green infrastructure has been identified as a potential adaptation strategy to minimise impacts from such events. A plethora of modelling approaches is available to assist decision makers in predicting the impacts of extreme rainfall events and assessing the potential for green infrastructure in response. Given the different technical (e.g. removal, efficiency) and non-technical (e.g. cost) characteristics of GI options (Jia et al., 2015), the selection of GI alternatives requires significant experimental and modelling investigations to test their efficiency in addressing flood risks (Baek et al., 2015).

In this article, we seek to provide clarity for decision makers in an emergent field by assessing how different modelling approaches evaluate GI options and their corresponding efficiency in minimising flood risks. Through a systematic literature review, this paper discusses the approaches used to assess the capacity of GI to minimise the impacts of extreme rainfall events under current and future situations in urban areas considering differing spatial and temporal scales. The questions this systematic review seeks to answer are: "How do different approaches for modelling current and future impacts of rainfall events incorporate GI?", "How do models address differing spatial and temporal scales?", and "What aspects related to GI design and assessment are being considered?". Together this allows us to understand the core concern underpinning the review, which is "How can GI modelling be more useful for decision makers?".

Methodology

Pre-identification

A literature review first investigated a series of studies that incorporated GI in flood modelling to assess differing approaches for modelling current and future impacts of extreme rainfall events. These were identified through a systematic search of peer-reviewed literature (Web of Science and Scopus databases) following the protocol of Preferred Reporting Items for Systematic Literature Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009). This first screening resulted in more than 5,000 returns. It was, therefore, necessary to narrow that down to those which considered modelling impacts of extreme rainfall events using GI options.

Identification of potential studies

The pre-identification step informed the selection of key terms used to refine the search and narrow down initial results to a manageable size. Terms were now defined based on the research questions underpinning this paper: "How do different approaches for modelling current and future impacts of rainfall events incorporate GI?", "How do models address differing spatial and temporal scales?" and "What aspects related to GI design and assessment are being considered?"

Screening and eligibility

When combined, and after removal of duplicates, the dataset included 671 publications from different fields. Titles and abstracts of the publications were assessed to determine whether they were suitable for inclusion in the review. This step resulted in 167 publications which were then screened in full. Those with no primary focus on flooding were excluded, resulting in the selection of 50 studies to be included in the final review.

Content analysis

Using NVivo 12 Pro, the content of selected articles (n=50) was analysed and grouped based on the aim of the studies: (i) calculation and simulation of the hydrological performance of GI; (ii) estimating flood risk/damage; (iii) application of varying types and combinations of GI; (iv) governance perspective of the implementation of GI; (v) application of GI for Urban Water Management (UWM). The content analysis also resulted in the development of a set of exploratory questions (codes) to further analyse how publications dealt with aspects related to spatial and temporal scales, as well as GI design and assessment (see Table 1).

Table 1 - Themes and exploratory questions used to analyse publications content

Theme	Exploratory questions
Spatial Scale	What is the spatial scale covered by the study (e.g. whole catchment, single waterway)?
	What kind of urbanisation pattern does the study focus on (e.g. urban infill, peri-urban, or greenfield development)?
	What types of land-use are included in the study (e.g. residential, commercial, industrial)?
Temporal Scale	What range of historical rainfall data is used by the study?
	What range of future rainfall data projection is used by the study (e.g. climate change projections)?
	How does the study deal with past and future land-use/land cover change?
GI Design and Assessment	How does the study design and assess GI alternatives (e.g. single option, multiple options not combined, or combined multiple options)?
	How does the study deal with data paucity and quality?
	What GI implementation aspects are discussed (e.g. cost analysis, an optimal combination of GI, runoff management, suitable locations)?

Results and discussion

GI has the potential to both improve the health of ecosystems and build the system's resilience to climate change (Cole et al., 2017; Salata & Yiannakou, 2016). It provides a platform for integrating land-use and water resource planning and design over varying times and scales, including precinct and neighbourhood through to the whole of catchment (Dhakal, 2017; Jha, 2012). Furthermore, GI can increase urban and flood resilience by buffering vulnerable areas from flood events, providing long term stormwater quality/quantity improvement, and reducing urban heat island effect (Hughes & Sharman, 2015). To date, GI implementation relies heavily on modelling to deal with a range of spatial and temporal scales, as well as design and other assessments, such as cost or performance, yet the scope of advantages detailed in the literature is not captured in much of the analyses.

From a spatial dimension, the impacts of GI implementation have been typically studied and incorporated in two ways: as a single waterway or the whole catchment. However, the majority of the selected studies investigated GI options applied to single waterways making it difficult to get a more holistic picture of the role of GI in minimising the impact of extreme rainfall events at the catchment scale. More tellingly for land-use planning, urbanisation patterns do not seem to be a key determinant utilised by the publications in the selection of models to test GI alternatives; rather their selection focused on models' capabilities and richness of functions instead. This points to the need for further studies, perhaps focused on co-producing tools with end-users, which can not only better evaluate GI techniques at larger spatial scales but also consider urbanisation aspects in order to provide more evidence to support land-use planning and flood risk management.

Secondly, from a temporal dimension, a significant amount of publications focused only on the historical data for both rainfall and land-use and land cover. In particular, the temporal scale of rainfall data mostly focused on one decade of historical data. While some studies developed future scenarios based on detected trends, future changes to land-use and land cover systems were not a predominant trend in the publications analysed. These aspects were even less considered by publications applying social-technical perspectives. Additionally, all studies showed limited incorporation of climate change projections, despite the potential of GI to make a significant strategic contribution in reconciling future development demands with changes in future rainfall. This presents a considerable gap in knowledge for the scientific community to address.

Thirdly, among the identified hydrological models, SWMM is widely used for planning, analysis, and design related to stormwater runoff. The model allows the evaluation of combinations of GI controls to determine their effectiveness in flood risk management. The model also accepts the input of rainfall data - both historical and future - allowing a wide range of scenarios for simulation and analysis. This feature is significant as it allows the incorporation of climate change projections in the scenarios. However, the incorporation of climate change projections in the scenarios is not yet widely explored, having been used in few studies. Although GI options available in the models are limited, it was positive to note the most used ones worldwide are covered, such as bioretention cells, porous pavement, and green roofs.

Finally, while cross-sectional integration of some models enables meaningful improvements in the spatial analysis, more integration with land-use planning is still needed. This is particularly important when it concerns the incorporation of stormwater and flood risk management to create more resilient cities. For example, the combination of the hydrological approach with other methods, such as Technique for Order Preference by Similarity to an Ideal Solution - TOPSIS, Land Transformation Model (LTM), GIS, or others, offers value in permitting a more comprehensive assessment of the effects of extreme rainfall. Nevertheless, the advances in hydrological models does allow a straightforward analysis of the spatial distribution of floods, GI and their effects, which can inform plans and policies about the spatial distribution of risks, the impacts of the implementation of GI and even the spatial understanding of the effects of rainfall events in a given catchment. The next challenge is to link this more closely with the professional demands of decision makers, in particular spatial planners.

Conclusions and future work

Adopting a systematic literature review of 50 publications, the paper assessed different approaches to modelling current and future impacts of extreme rainfall events on the urban environment, including under conditions of climate change. It found that there were two main families of modelling approaches: hydrological and social-technical perspectives, and the aim of the study and choice of modelling approaches provided very different ways to evaluate current and future impacts of extreme rainfall events. After reviewing the utility of these two families of modelling approaches with respect to how they spatially and temporally incorporated GI, our study identified two key findings that serve to provide the basis of a future research agenda and which offer potential to improve implementation. First, the information generated by current GI modelling approaches are not well integrated into the demands of land-use planning, and may more reflect the information availability than useability. Second, there are particular gaps with regard to understanding future risks and pressures, most notably increased rainfall intensity, escalating development demands, and the interaction between the two. It was surprising to note that climate change projections and land-use futures were only rarely included in the models, despite their potentially high value for decision makers struggling to reconcile competing demands.

References

Cole, L. B., McPhearson, T., Herzog, C. P., Russ, A., Russ, A., & Krasny, M. E. (2017). Green Infrastructure. In U. P. S. Online (Ed.), *Urban environmental education review* (pp. 8): University of Cornell University Press.

Dhakal, K. P. (2017). *Climate change impact on urban stormwater system and use of green infrastructure for adaptation: An investigation on technology, policy, and governance* (PhD). Southern Illinois University Carbondale. Retrieved from http://opensiuc.lib.siu.edu/dissertations/1479

Hughes, J., & Sharman, B. (2015). Flood resilient communities: A framework and case studies. *Asia Pacific Stormwater Conference*, 23.

Jha, A. K. (2012). *Cities and flooding a guide to integrated urban flood risk management for the 21st century*. Washington, D.C.: World Bank.

Salata, K., & Yiannakou, A. (2016). Green Infrastructure and Climate Change Adaptation. *Tema-Journal of Land Use Mobility and Environment, 9*(1), 10-27. https://doi.org/10.6092/1970-9870/3723