Moving from reliability to resilience-based evaluation of urban drainage infrastructure: A case study of Kampala, Uganda

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Extended Abstract

The performance of existing urban drainage systems (UDSs) in various cities is increasingly threatened by multiple and uncertain threats such as climate change, rapid urbanisation and infrastructure failure which lead to negative flooding impacts and consequences. However, conventional urban drainage design and rehabilitation approaches tend to focus on minimising the probability of *hydraulic failures* resulting from a chosen design storm as a basis for determining the flood protection service level delivered by a given system (Butler and Davies, 2011; Sun et al., 2011; Thorndahl and Willems, 2008). Such hydraulic-reliability based approaches may be insufficient for ensuring accepteable flood protection levels in cities during unprecedented extreme events. Consequently, to enhance the resilience of UDSs, new and computationally efficient evaluation approaches that can enable explicit consideration of vital interactions between *threats*, system *performance* and resulting *failure impacts* during both *normal* and *exceptional* loading conditions are required (Butler et al., 2014; Kellagher et al., 2009; Mugume et al., 2015).

UDS resilience is investigated using a case study of the Nakivubo UDS that drains a highly urbanised catchment in Kampala, Uganda (Figure 1). Over the last decade, Kampala has experienced an increase in the number of pluvial flooding incidences with negative consequences such as property damage, traffic disruption and shallow ground water contamination among others (Lwasa, 2010; Sliuzas et al., 2013; UN-Habitat, 2009). The main causes of flooding in Kamapala include: extreme rainfall (caused by climate change and variability), rapid urbanisation, insufficient drainage infrastructure and inadequate system cleaning and maintenance.

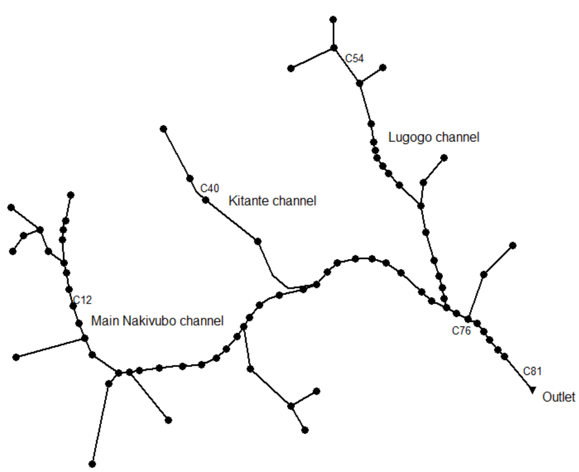

Figure 1: Layout of the modelled Nakivubo urban drainage network (Mugume et al., 2015)

In this research, the Global Resilience Analysis (GRA) approach (Mugume et al., 2015) is extended to investigate the effect of a wide range of random functional failure scenarios (extreme rainfall) with varying *magnitude*, *duration* and *spatial distribution* on the ability of the case study UDS to minimise the resulting magnitude and duration of flooding (loss of system functionality). The developed GRA method applies *block rainfall events* (Figure 2) derived from observed extreme rainfall data (IDF) curves for Kampala as opposed to use of design rainstorms. Use of block rainfall events for UDS model simulations enables more accurate assessment of maximum loss of system functionality for a given return period and duration (Mugume and Butler, 2015). Functional failure is modelled through random and cumulative loading of subcatchments with specific block rainfall events to simulate hydraulic overloading that leads surface flooding. A large number of model simulations are run in a MATLAB environment linked to the Storm Water Management Model, SWMM v5.1 (Rossman, 2010). UDS performance is quantified at each considered failure level using using total flood volume and mean duration of nodal flooding as key system performance indicators.

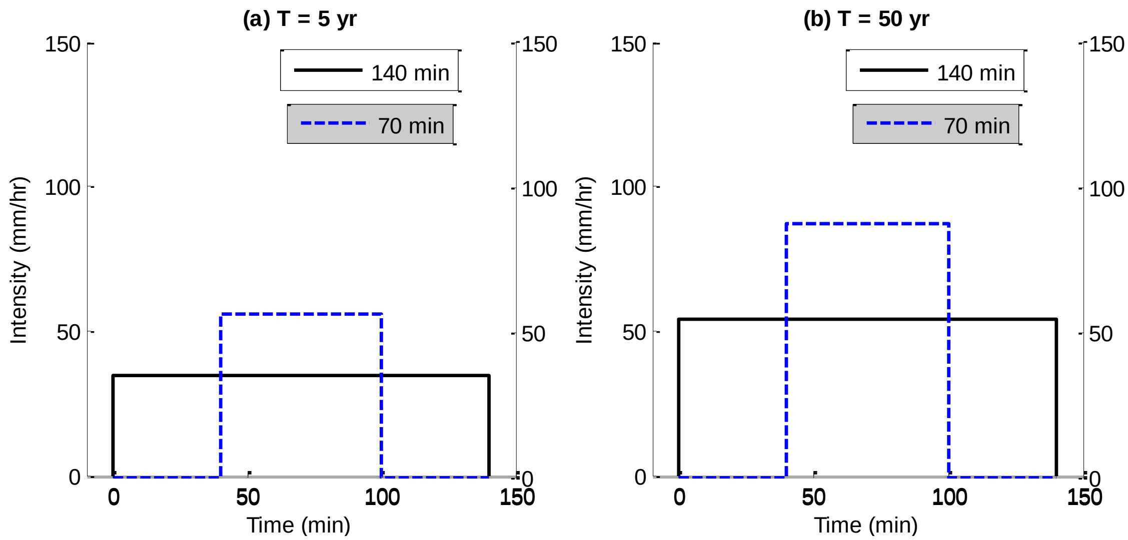

Figure 2: 140 minute block rainfall events derived from IDF curves for Kampala, Uganda for *T* = 5 & 50 years. The blue dashed lines show the corresponding 70 minute block rainfall events (Mugume and Butler, 2015).

The study results indicate that the 70 minute block rainfall events lead to significant loss of system functionality magnitude but have less effect on flood duration when compared to corresponding 140 minute rainfall events. The results also indicate that for both 140 and 70 block rainfall events, degradation of system functionality is exacerbated by increasing spatial rainfall distribution and return period (Figure 3). This suggests that the residual hydraulic conveyance capacity of the existing UDS is significantly reduced by occurrence of short duration high intensity rainstorms, indicating that the system exhibits low levels of resilience to extreme rainfall. Because the short duration events lead to higher loss of functionality magnitude but less effect of duration, it is suggested that implementation of innovative multifunctional infrastructure for example intentional design of specific road network sections to enable safe conveyance of exceedance flows could provide a promising option for enhancing global resilience to extreme events in Kampala.

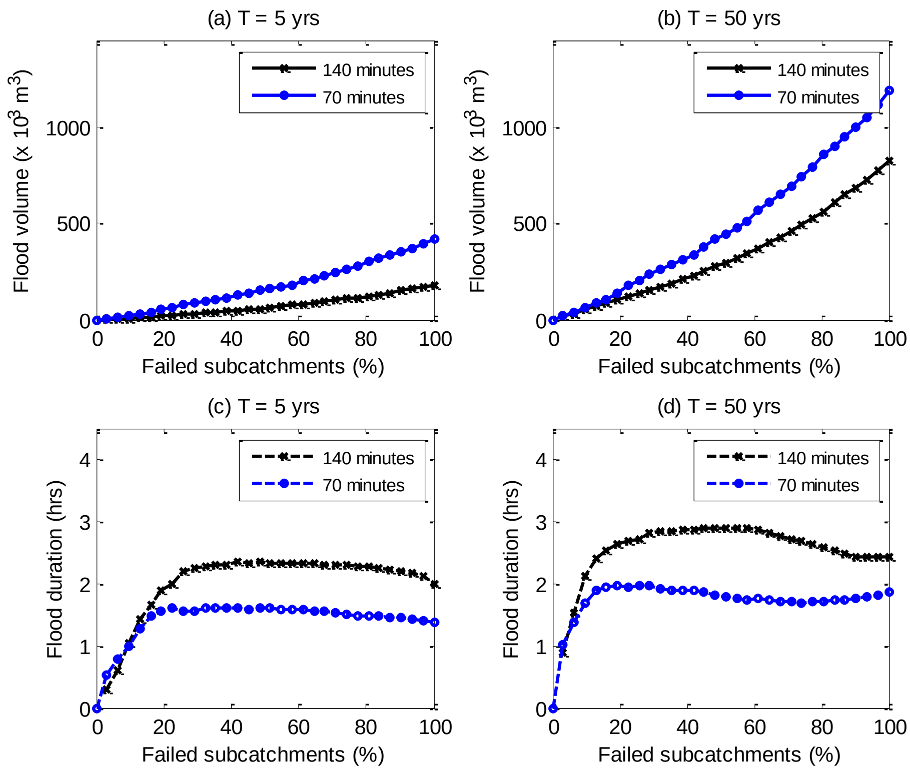

Figure 3: GRA results for the existing Nakivubo UDS when subject to random cumulative functional failure

It is further concluded that using the proposed GRA approach facilitates more realistic evaluation of system performance under a wide range of spatially distributed rainfall inputs and could thus minimise potentially erroneous and costly adaptation decisions by ensuring more accurate design (sizing) of resilience enhancement strategies such as distributed storage or dual-purpose RWH systems in cities.

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