SPATIAL PLANNING INSTITUTIONS IN URBAN FLOOD MANAGEMENT IN KAMPALA AND KIGALI AND THEIR IMPLICATIONS FOR INTEGRATED SPATIAL MODELLING

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ABSTRACT. *Recent research has looked at questions of flood management in Kampala, Uganda in the context of climate change by combining an urban development model and a dynamic flood model. This work is now being extended to include Kigali, Rwanda. Both Kampala and Kigali face enormous and complex developmental problems: relatively weak economic performance; the urbanization of poverty; relatively poor infrastructure (roads, public transport, water, sanitation, health, education, etc.); complex environmental management issues including regular flash flooding; etc.. Both Kampala and Kigali have recently prepared new urban plans that are now being implemented. The paper examines three main issues: what policy instruments for urban growth management and flood management are in place in the two cities; to what extent do their governance environments allow these instruments to be effectively applied; how such differences could or should influence the design and performance of integrated urban flood modelling approaches. Our analyses from Kampala suggest that ineffective of urban planning and management procedures are a significant factor in increasing storm water run-off rates and discharge as well as in increasing the level of exposure of communities to flooding due to the occupation of flood prone areas. In Kigali, where urban planning and enforcement has recently become stronger, integrated models may still provide useful insights into potential problems through ex-ante evaluation of the impact of urban development projects.*

1. Introduction

Recent research has looked at questions of flood management in Kampala, Uganda in the context of climate change by combining an urban development model and a dynamic flood model. The Integrated Flood Management Project Kampala (IFMK) was undertaken by a consortium led by ITC in the city of Kampala (Sliuzas, Flacke, & Jetten, 2013). In this project, a series of land cover modelling exercises based on spatial logistic regression methods (Fura, 2013) and cellular automata (Pérez-Molina et al., 2015a) were completed for the Upper Lubigi sub catchment and for the Kampala metropolitan area (Abebe, 2013). The openLISEM model (De Roo et al., 1996) was calibrated for Upper Lubigi by prof. dr. Victor Jetten (see an analysis of this model in Habonimana, 2014); Mhonda (2013) used this model to assess the impact of non-conventional interventions, such as rainwater harvesting, infiltration trenches, and retention ponds on storm-water discharge and flooding. The land cover scenarios developed in Fura (2013) and Pérez-Molina et al. (2015a) were later used to simulate the consequences on flood impacts of urban development (Sliuzas, Flacke, & Jetten, 2013; Sliuzas, Lwasa, et al., 2013), in combination with other measures (such as improvement of the drainage system). The openLISEM flood model of Upper Lubigi provided the capacity for flood simulation.

While results from the Kampala experience were directly applicable to urban management in this city, they also provided an appropriate platform to formulate more general research questions. Particularly, to what extent can land use planning reduce the impact of flood hazard in urban contexts? The experience of Kampala provided important insights on infrastructure investment as a tool to reduce flood hazard; but since enforcement of land use controls is deficient, broadening the scope of analysis to the city of Kigali –were regulation is more stringently applied– is expected to generate a wealth of knowledge, especially when comparing both cases and by setting them within the more general context of Sub-Saharan African cities.

2. Opportunities to advance knowledge through comparative case studies

The cities of Kampala and Kigali, and the countries of Uganda and Rwanda, present striking similarities. As discussed by Goodfellow (2013), Ugandan and Rwandese national economies are largely agricultural-based but have been reporting very high economic growth rates over recent years (Annual change in GDP for 2008-2013: Rwanda 8.4% p.a. and Uganda 5.74% p.a. (APP, 2014)) poverty levels are similar (according to UNDP in 2010-2011 both have around 71% population suffering multi-dimensional poverty), both have a low Human Development Index (HDI 2013 for Uganda is 0.484 and that of Rwanda is slightly higher at 0.506) (http://hdr.undp.org/en/data) and political regimes have a shared background.

The cities themselves also present similarities. The have similar overall population levels (estimated for 2015 at 1.9 million residents in Kampala and 1.3 million in Kigali). Physically, they are located in a hilly terrain with wetlands occupying the low elevation areas (Kampala appears to have preserved the natural vegetation of these areas better, although encroachment into the inundated area by industry and housing is larger, with Kigali having occupied them with agricultural fields and some industries and housing). Both cities are also growing at a yearly rate of 4% (est. for 2010-2015), although when land patterns are analysed, the level of dispersion in urban development is much larger for Kampala than for Kigali (Fig. 1).

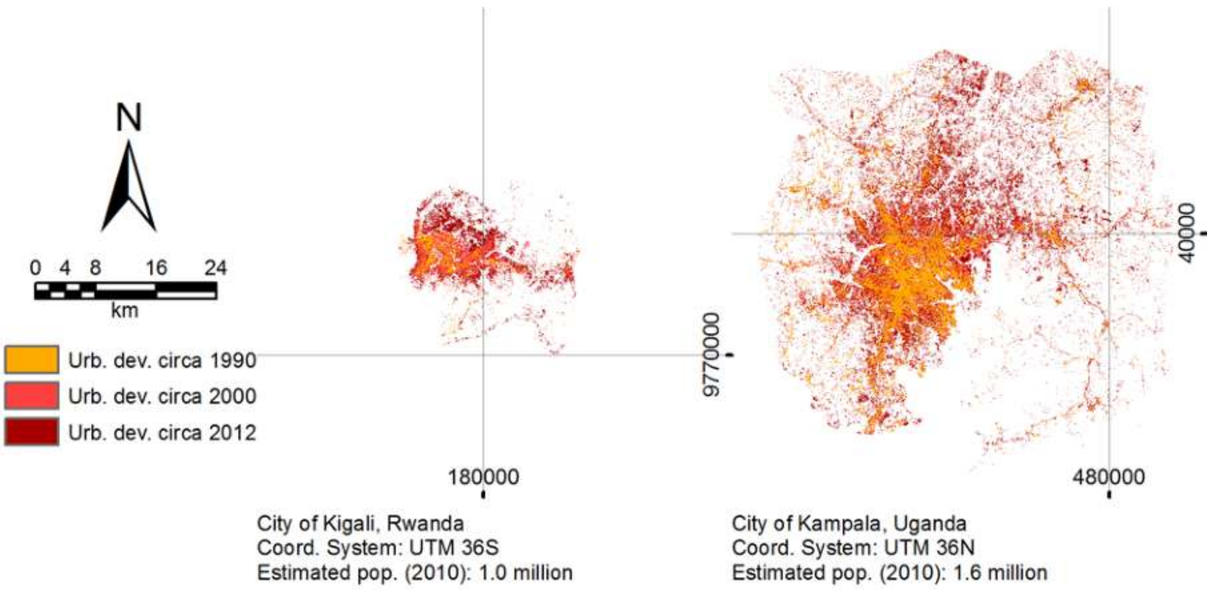

Figure 1. Urban development trends for Kigali and Kampala

Further, the challenges faced by both cities are also comparable. Both cities show important limitations in infrastructure provision (roads and public transportation, water and sanitation, and notably drainage systems). However, they do diverge in one fundamental way: the willingness of enforcing land use controls, which Goodfellow (2013) ascribes to "fundamentally different political bargaining environments". Whereas in Kigali, the central government's commitment to implementation of land use plans created a "virtuous cycle" encouraging both local authorities to enforce plans and urban dwellers to comply with them, Kampala presented the opposite situation: both elite *and* popular groups could effectively sidestep decisions by the City Council by appealing to higher levels of government (in turn, de-incentivizing local authorities' will to enforce urban regulations). Moreover, in Kampala many large landowners such as religious groups and the Buganda King who owns much of Kampala's wetlands, allow leasehold access to their lands for group members or citizens, and development of such lands are often poorly regulated by government officers (Muinde, 2013).

A comparison of these two very similar cases, with such a contrast in urban management practices, offers an interesting opportunity to assess the differences introduced by land use planning.

2.1 Land use planning instruments
Both Kampala and Kigali have recently prepared new urban plans that are now being implemented. The Kampala Physical Development Plan (KPDP) was approved by the City Council in April 2013[1]; the Kigali Master Plan (KMP) was finalized in 2013, based on the conceptual plan existing since 2007[2].

When comparing both documents, one can conclude that both plans have a strong focus on physical development and in particular land use (zoning) and regional transportation. Transportation, further, also adopts the same technological solution – bus rapid transit, complemented by regional road systems and at least mentioning non-motorized modes. But there is a difference in the level of detail of the land use provisions in each plan.

- The KPDP generates a conceptual proposal, including identifying new satellite towns to be reinforced as well as suitability analysis for urban development. Some sketches of possible future (re)development options are provided for some localities such as the city centre, but mostly it is a conceptual plan.
- The KMP goes into greater detail, to the point of identifying and proposing conforming, conditional, and non-conforming land uses (e.g. in the Natural Environmental Management Strategies section). More detailed district level development plans are also used to guide development application and approval processes.

This difference is also apparent in the conceptualization of flooding within the plans. Thus, in Kampala, flooding is addressed in the section corresponding to infrastructure, assuming the solution of drainage systems. Indeed, coordination between urban development and drainage systems is proposed, emphasizing detailed design of drainage systems and adequate funding to accommodate future growth (the IFMK fits perfectly within this scheme by developing one such urban development/drainage capacity analysis for the most critical area, the Upper Lubigi basin corresponding to the Kawempe division, which is expected to have significant development due to its suitability for urban land uses), with detailed land use planning having the role of preventing further encroachment of urban land uses on flood prone areas, a role which until now has been largely unsuccessful.

In contrast, the KMP deals with flooding in the Natural Environmental Management Strategies section (of the city level master plan report). The relationship between flooding and urban development is posed in terms of protecting the natural value of wetlands –which might seem contradictory, since many of the wetland areas are not occupied by natural vegetation, unlike Kampala, although urban encroachment into them is also much more limited than in Kampala. Specific goals of the plan include zero loss of existing wetlands (to urban development) and riparian buffer zones from wetland fringes and from drainage (20 to 50 m); the elements suggested in the proposed storm water system (in the infrastructure section) are vegetated and bioretention swales, bioretention basins and constructed

[1] http://www.observer.ug/component/content/article?id=32676:-kampala-is-making-headway
[2] http://www.kcps.gov.rw/index.php?id=21

wetlands; these have the goal of re-using storm water for beautification and non-potable water source, rather than merely channelization of storm water. (The KMP does consider the 2008 Storm Water Master Plan to be in line with its own vision.) Recently Kigali City has relocated several industrial and housing areas out of wetlands and commenced an ecological restoration project in two large wetlands. Further displacements from wetlands are also envisaged.

2.1 Enforcement of land use controls in Kigali, Rwanda

Figure 2 illustrates a case of large scale relocation of an informal settlement originally located in a wetland; the area was transformed into roads and green space. According to Republic of Rwanda, Ministry of Natural Resources (2013), residents of the centrally located Ubumwe slum –a densely populated area with "dilapidated and unhygienic" buildings– were moved to Batsinda, a fringe area at about 5 km distance from Ubumwe. This space is to be partly re-developed for commercial land use but, since part of it is in close proximity to the wetland, a grass buffer will be maintained in its north-east part.

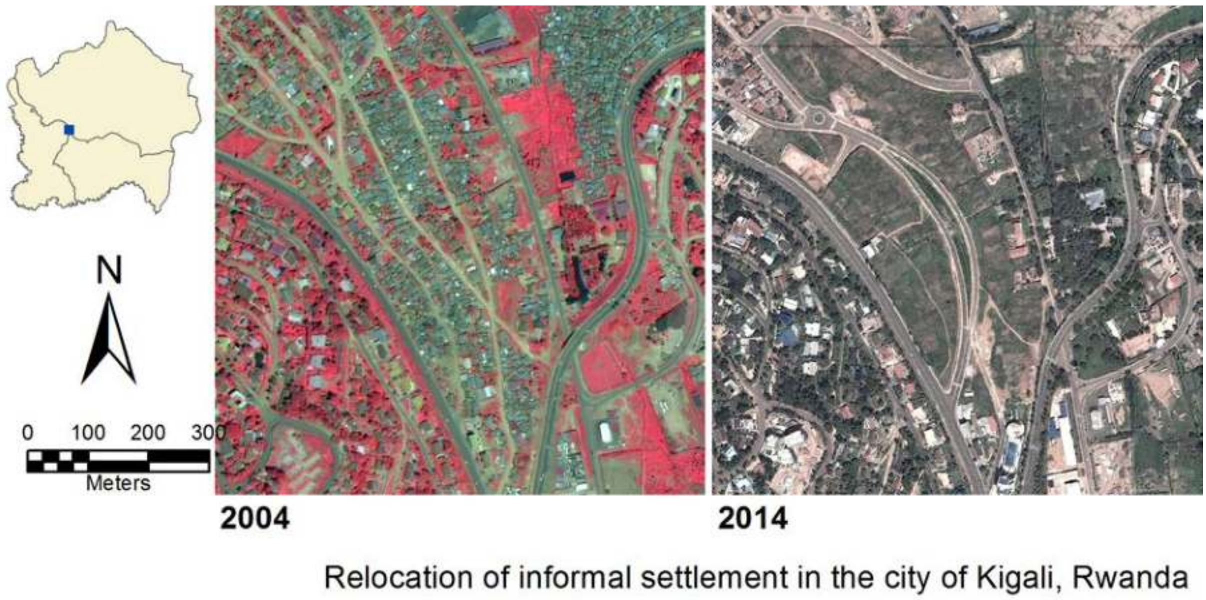

Figure 2. Example of enforcement of land use controls via displacement in a wetland area of Kigali

2.2 Infrastructure drainage system investment in Kampala, Uganda

The landscape of Kampala consists of 8 main catchment areas, each draining into a broad and very gently sloping wetland area; some wetlands drain directly into Lake Victoria while others channel water into neighbouring local government areas and eventually into rivers and lakes. Kampala itself does not contain any rivers as such, though each wetland does include both natural and artificial channels .

Kampala's drainage system is, however, poorly developed and managed. There are 8 primary drainage channels, two of which have been recently upgraded according to the 2002 Drainage Master Plan (KDMP): the Nakivubo channel that drains much of the city centre area feeds into Lake Victoria and the Lubigi channel that drains much of the north western parts of Kampala and feeds into Lake Mayanja Kato to the west. To date the upgrading of the Lubigi channel has been limited to its upper reaches only. Upgrading was undertaken through a combination of channel widening and lining and the installation of high capacity culverts at bottlenecks such as under roads. Recent flood events show that such improvements may not always be sufficient. In 2014 a new project to update the 2002

KDMP was started but this too was focussed on the primary drainage systems, albeit with more attention for Sustainable Drainage System (SuDS) options than was apparent in the KDMP. Secondary drains do exist but are of variable quality and durability; some are constructed with lined channels but many are in a more natural state and poorly maintained. Tertiary drains, where they exist are frequently community-made and poorly maintained.

Drainage systems form part of any city's basic infrastructure, however, there are many ways in which they can be designed and managed. In Kampala's case, given the relatively weak technical, financial and human capacity of the city administration, it is especially important to consider the implementability and sustainability of all planning and engineering options. One of the major proposals of the IFMK project is to adopt a SuDS principles in drainage design, especially in case of new developments and the foreseen growth of Greater Kampala's population to as much as 8-10 million by 2040. A SuDS approach can utilize the natural capacities of the landscape to manage surface water runoff to reduce peak discharges and, in so doing, reduce the investments required for traditional drainage systems. The approach can also be combined with community based management practices for solid waste management, protection of natural wetlands etc.. Their ultimate success will also require improved regulation and control of urban development activities. Improved understanding to the combined effects of such measures can be assessed through modelling activities that can provide insights into the relative merits of different mixtures of measures and behaviours. The construction of the Northern Bypass alongside the Lubigi Channel for example has significantly reduced traffic load in the city centre but aggravated pluvial flooding in some areas and necessitated the forced displacement of multiple households. Such effects can be foreseen through ex-ante model based analyses that may lead to modified designs and decision making, or at the very least more timely displacement in view of the changed flood risks in certain locations.

Figure 3. Improvement of primary drainage channel in Bwaise, Upper Lubigi, Kampala 2013
(photo taken from Habonimana, 2014)

3. Modelling framework and application

The approach applied during the IFMK is of widespread use in the field, especially in recent years, when computational power has increased: it consists of a land use/land cover component and a flood component. In essence, land cover patterns are researched (and generally base line conditions are used to simulate future land cover conditions). The output of this analysis is then used as input to a rainfall-runoff model, which in turn can be used to simulate the flow of runoff over the landscape –and detect any flooding, should it occur.

From a scale perspective, the final objective is to analyse a key catchment within the city. The strategy is to develop an analysis pilot case study, ideally in a critically important area (i.e. an area undergoing rapid change that increases flood risk in it). This pilot can later be replicated by local authorities in other catchments; it serves to develop specific modelling products, pertinent for the context being explored, while generating knowledge that informs higher level theoretical models of urban and environmental dynamics.

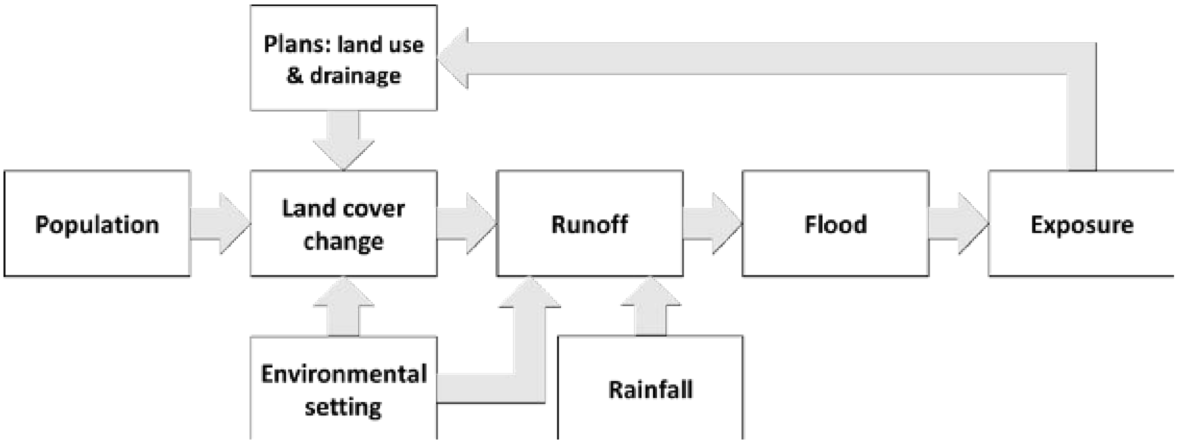

Figure 4. Conceptual framework

Land use/land cover simulation for Kigali and Kampala has included two approaches: spatial logistic regression (SLR) and cellular automata (CA). SLR, in turn, has been performed at city-wide scale and also for the specific catchment being analysed. Smaller scale studies of specific functional aspects (e.g. runoff generation) or of design have also been used to complement the overall narrative. Flood modelling has been performed using the openLISEM flood model, a rainfall-runoff-flood model appropriate for mid-scale analysis. openLISEM has the advantage of receiving as inputs land cover and rainfall data, as well as an infiltration map, and producing a diversity of spatially explicit flood measures.

4. Discussion on modelling for policy and findings

4.1 Land use dynamics modelling

Sliuzas et al. (2013a) synthesized integrated results of the IFMK project: spatially explicit scenarios of land cover change, projecting land cover conditions to 2020 (assuming trend and high population growth), were used as inputs into the flood model of the Upper Lubigi catchment in Kampala, Uganda. Twelve scenarios were simulated: a baseline scenario with unimproved drainage and baseline year (2010) land cover; a set of scenarios with improved primary drain and clean secondary drains; a set of scenarios in which the secondary channels were grassed waterways (increasing infiltration); a “Zone” scenario considering the removal of built up flooded in the baseline conditions (replaced with grass), and a scenario were 15 thousand house owners increased grassed area in their plots. Output results included flood depth maps, total flooded area, discharge and flood volume, as well as quantification of the number of structures flooded in each scenario.

Future land cover scenarios used in Sliuzas et al. (2013) were developed using the SLR results of Fura (2013). This analysis was carried out on 10m square cells; the predicted land cover category was built up (designated as 1 or 0). Identified drivers of land cover (built up) included: proportion of surrounding built up, distance to CBD, minor roads, industrial sites, and to major roads (positively correlated with probability of being built up) and slope, distance to market centres, streams and proportion of undeveloped land surrounding the cell (negatively correlated). The predicted probabilities were used as a suitability score to spatially allocate future urban development.

SLR predictions, however, have two problems: firstly, they tend to over-cluster the predicted landscape pattern; this is shown in figure 5, where most cells correspond to the 40 to 60% built-up category. Secondly, it is difficult to use them to generate land patterns deviating from the trend conditions (e.g., for Kampala, it would be difficult to model the effect of stronger land use plan implementation, since enforcement has been historically weak). Therefore, in a second stage, a simple CA model was developed (Pérez-Molina et al., 2015a). This model was based on defining a simple suitability measure, including percentage of built up in neighbouring cells, wetlands, non-vegetation percentage, and distance to CBD. It is a simplified version of the SLR; factors were chosen and weighed in such a way as to replicate trend conditions (with the advantage that any new suitability index, based on the researchers interest, could be defined and used to simulate alternative land patterns).

Unlike the SLR of Fura (2013), the CA model used a 20m-side cell as the basic geographic unit. Each cell (automaton) was characterized by the percentages of built up, vegetation, on-road bare soil, off-road bare soil, tarmac, and water within it. Also associated to each cell was a potential condition, such that built up and on-road bare soil both increased (randomly but with the overall basin conforming to a statistical distribution consistent with historic urban development) and other categories declined. The model selects the most suitable cells and, to simulate future landscape, assigns to these the potential (future) urban condition. Further, this potential condition can be modified to reflect policy constraints (e.g., no land cover change was defined for institutional land uses such as the Makerere University campus).

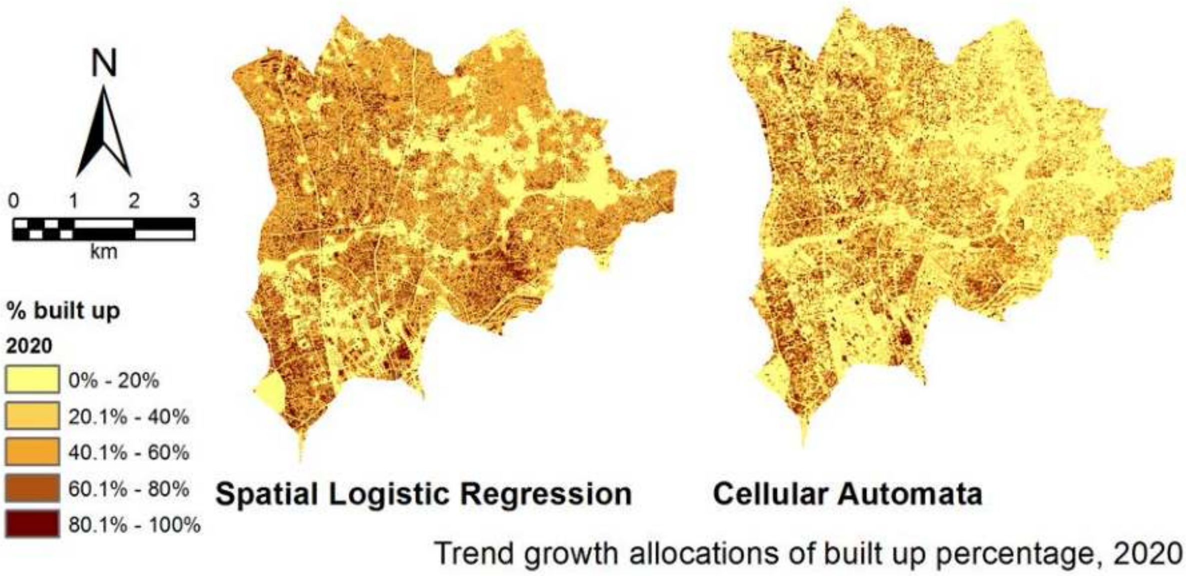

Figure 5. Comparison of simulated scenarios of urban development for Upper Lubigi, Kampala

For Kigali, Nduwayezu (2015) recently completed a SLR modelling exercise using Landsat (mid-resolution) satellite imagery to derive land cover, describe land pattern changes, and identify determinants. As in the work of Fura (2013) and of Abebe (2013) for Kampala, the neighbourhood factor –percentage of built up surrounding the cell– was identified as the main determinant of land cover change. Nduwayezu (2015) simulated trend conditions and found troubling potential problems, such as possible deforestation and occupation of wetlands in the western part of Kigali.

All of these models have formalized built up land cover as a single category, which is treated as the sole dependent variable; even the CA model implicitly does this, since the percentage of on-road bare soil is determined by the increase in built up land cover and other categories (vegetation, off-road bare soil) decrease proportionally to their base line values. For future extensions, two key modifications are being analysed:

- The disaggregation of built up into a set of land use/land cover categories (specifically, formal high density built up, formal low density built up, industrial, and informal). It is expected that urban growth simulations will be both easier and richer, in the sense of providing more information, than a single entity; further, policy simulation would also be eased, given that many policy targets vary per building typology. However, this decision also means better land use/land cover data models must be generated in data sparse environments.
- An exploration of the relationship between non-built up land cover categories and their dynamics. A recent analysis (Pérez-Molina et al., 2015b) detected that only a few land use scenarios differing in the distribution of built up land cover caused differences in flood impacts. However, if the proportion of off-road bare soil and vegetation were modified, hydrological impacts do substantially change; in particular they are much smaller for larger vegetation percentages. This finding suggests that it may be critical to better understand how vegetation changes within the urban landscape and how such changes affect the processes of water retention, infiltration and runoff; additionally, sustainable urban drainage systems and other forms of local infiltration could be re-assessed, in light of this result, as possible policy measures to reduce flood impacts.

4.2 Flood modelling

openLISEM (documented in the webpage http://blogs.itc.nl/lisem/) is an event-based rainfall-runoff-erosion-flood model. It transforms total rainfall falling over a catchment into runoff by subtracting various fractions, depending on landscape characteristics and conforming to several physical processes: soil hydrological characteristics and initial humidity result in an estimate of the infiltration fraction; a vegetation land cover map triggers interception, as does a housing (built up) land cover map; roads and housing introduce total or partial imperviousness of the soil (no infiltration). Once runoff has been determined for an initial time step, rainfall will vary for the second timestep according to a hyetograph and overland flow will be accumulated towards the channel system, from which the landscape may eventually be inundated.

openLISEM, and the PC Raster platform on which it was built, have been used to explore how different elements can be incorporated into the drainage system (or upstream) to reduce runoff, and what general impact they cause on hydrological outcomes.

Habonimana (2014) explored the impact of the spatio-temporal variation of rainfall on flood estimates for Upper Lubigi, Kampala. Both Kigali and Kampala are data sparse environments (to the point that, for Kampala, a rain gauge was installed in order to generate basic data for the IFMK project), with the consequence that simulations are generally performed with point rainfall data assumed as valid for the entire catchment (see Sliuzas et al., 2013). However, Habonimana's (2014) results suggest that spatial variations of intensity may indeed impact hydrological outcomes in unforeseeable ways (some areas over predicting and others under predicting, relative to a constant intensity); at the very least, more attention should be paid to this issue and perhaps uncertainty should be addressed by simulating various rainfall events.

Mhonda (2013) tested three strategies to promote local infiltration (rooftop rainwater harvesting, infiltration trenches, and retention ponds); he found rainwater harvesting to have, by itself, negligible effects. But the combination of all measures was argued to be the best option in reducing runoff, with peak discharge at the outlet being up to 25% less than peak discharge without any measure.

These case studies show the versatility of openLISEM in incorporating pertinent policy measures, in line with alternative approaches to drainage systems (such as sustainable urban drainage systems) that prioritize local infiltration of runoff. The calibrated openLISEM models for Kampala, Uganda (specifically for the Upper Lubigi basin) assumed certain simplified land cover conditions. For example, all built up units were of the same type (although, as can be seen, barrels for water harvesting for some of these could be simulated) and vegetation is also assumed constant. Would variations to these aggregate categories be useful or are they necessary? This question is particularly important for the vegetation fraction, currently also being treated as constant in the land use dynamics models.

4.3 Findings on the case studies

In both cities, the development and use of such models, and the capacity to use them in local decision making across various spatial and temporal scales can contribute to a strengthening of the evidence base of planning and management decisions.

Our analyses from Kampala suggest that ineffective urban planning and management procedures are a significant factor in increasing storm water run-off rates and discharge, and perhaps more importantly in increasing the level of exposure of communities to flooding due to the occupation of flood prone areas. A pre-requisite for the enforcement of wetland protection and a development moratorium in flood prone areas is information on their location and extent. Such analyses are, however, not just technical exercises. Implicit in such a spatial definition of flood proneness is a political discussion of acceptable risk, as the flood extent varies according to the return period of the rainfall (i.e. a 1:100 year event will generate a larger flood extent that a 1:10 year event). Moreover, if flood zones are to be created and enforced these should also consider the effects of future developments within the catchment and perhaps also the effects of climate change.

In Kigali, where urban planning and enforcement has recently become stronger, integrated models may still provide useful insights into potential problems through ex-ante evaluation of the impact of urban development projects. The examination of longer term scenarios related to climate change could also be beneficial, though as in Kampala, they are likely to be less critical in the short term.

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