TITLE

Integrated Flood Risk Management in Slums - Applying 1D Modelling in Kibera, Nairobi

Authors

Joe Mulligan CEng MICE ACGI LEED AP BD+C

Associate Director, Kounkuey Design Initiative (www.kounkuey.org)

Industrial PhD Student, KTH Royal Institute of Technology

Nilani Venn MSci MSc C.WEM CEnv MCIWEM

Senior Engineer, Cities - Water, BuroHappold Engineering (www.burohappold.com)

Rodoula Gregoriou MEng

Engineer, Cities - Water, BuroHappold Engineering

Duncan Ker-Reid MEng CEng MICE ACGI

Associate, Cities - Water, BuroHappold Engineering

Alan Travers CEng, BSc, MICE, MCIWEM

Partner, BuroHappold Engineering

Contact details

joe@kounkuey.org

+46 (0)73 073 2109

www.kounkuey.org

ABSTRACT

In cities in the developing world, rapid urbanization and climate change are combining to dramatically increase exposure to flood risk among the poorest and most vulnerable. Half of Nairobi's three million residents live in informal areas, which are consistently located on the city's major watercourses. Kibera, Nairobi's largest slum, located on the Ngong River, is subject to significant flood risk with over 50% of residents reporting their houses flooded in the 2015 'long-rains'.

In 2015-2016 Kounkuey Design Initiative and BuroHappold Engineering delivered an action-research program to model the fluvial flood risk in Kibera, integrating 1D hydraulic modelling with resident-collected data. In a 'first-of-its-kind' experiment in this context the outputs were applied in the development of flood risk awareness exercises and built projects in the settlement. This paper discusses the rationale and process of developing the model; the collection of field data in challenging environments, model validation using community collected data and application at various scales of project design. Recommendations are made for the application of this type of tool in other urban-informal contexts, integration with existing city infrastructure planning and the potential for knowledge transfer using accessible modelling software.

Abbreviations

DRM - Disaster Risk Management
DTM - Digital Terrain Model
FRM - Flood Risk Management
GIS – Geographic Information System
KMD - Kenya Meteorological Department
KDI – Kounkuey Design Initiative
NRBP – Nairobi River Basin Project
NCC – Nairobi City County
ODK - Open Data Kit

Keywords

Developing Countries, Design methods & aids, Floods & floodworks, Hydraulics & hydrodynamics, Risk & probability analysis, River engineering, Sustainability

1. Introduction

Floods are the most frequent of all natural disasters (Jha et al, 2012). In cities in the developing world, rapid urbanization and climate change are combining to dramatically increase exposure to flood risk among the poorest and most vulnerable (ibid).

The informal settlements of Nairobi are consistently located on the city's major watercourses (Karisa, 2010). Kibera, Nairobi's largest informal settlement, is subject to significant flood risk due to poor drainage and its location adjacent to the Ngong River, with over 50% of residents (from a 963 household panel survey) reporting their houses flooded in the 2015 March-April-May so-called 'long- rains' (Mulligan et al, 2016). The issue was brought to the attention of a broad cross-section of Nairobi residents during the same period when a severe rainfall event (116mm recorded in 24 hours (KMD, 2015) affected the whole of the city.

Flood risk management capacity in Kenya is evolving and has historically focused on rural areas. Limited government data, access and interface with informal urban areas makes flood awareness, preparedness and planning processes difficult, while regulatory and political constraints limit larger infrastructural interventions. At the same time, the Kenya Flood Mitigation Strategy (MOWI, 2009) looks to introduce Integrated Flood Management. At the County level local authorities are seeking to address this issue, which is at the top of the agenda for many residents in both formal and informal parts of the city.

In order to investigate some of these challenges in the informal context the Nairobi-based non-governmental organisation Kounkuey Design Initiative (KDI) and UK-based BuroHappold Engineering delivered an action-research program in 2015-2016 to model fluvial flood risk in Kibera and to integrate the hydraulic modelling with resident-collected data on vulnerability and risk. The outputs of the modelling process were applied in the development of flood risk awareness exercises as well as built projects in the settlement in 2016. The model was handed over to KDI in early 2017.

This paper discusses the specific challenges in Kibera and other informal areas within the Kenyan and international policy context. It then goes on to describe the rationale and process of developing the model; the collection of field data in Kibera; model validation using community collected data and its application at various scales of project design. Graphic outputs from the modelling process are presented. Finally, recommendations are made for the application of this type of tool in other urban-informal contexts, integration with existing city infrastructure planning and the potential for knowledge transfer using accessible modelling software.

Data sources for this study include:

1) a 963 survey of households in high-exposure areas in Kibera delivered by KDI pre- and post the long-rains by KDI between March and June 2015;

2) thirteen Key Respondent Interviews undertaken between June 2015 and May 2016 by KDI with representatives from different institutions whose work relates to FRM and DRM (results at KDI, 2017);

3) BuroHappold project documentation from the delivery of the hydraulic model.

2. Urban Flood Risk Management in Kenya

The FRM policy context is evolving as national governance structure changes and as international practice influences policy. As in many other countries the trans-boundary and trans-ministry nature of flood management is a challenge - one government respondent noted: ‘At the moment FRM is a cross cutting issue, and when it is everyone’s business it is no-one’s business’.

The most recent Kenya Flood Mitigation Strategy (MOWI, 2009) is based on the concept of Integrated Flood Management. While there has been some success in integrated projects in the rural areas (for example in the Western Kenya Community Driven Development and Flood Mitigation Project in Budalangi) there is limited evidence of the use of integrated flood management in urban contexts in Kenya. Cities such as Nairobi with large numbers of residents living in riparian zones present particular challenges. There are a number of policies in place to address rivers and riparian zone conservation, namely: The Water Act Cap 372 (2002), The Physical Planning Act CAP 286 (1996), and the Survey Act 299 (2009). These acts prescribe the dimensions distance from river’s edge of riparian buffer zones and the activities that are excluded. According to The Water Act Cap 372 (2002) - which is most applicable - the riparian reserve has a range of 6-30 metres within which all structures are deemed illegal.

Although these laws exist, they do not by themselves address the specific conditions of urban riparian zones. In addition, there have been areas of overlap of mandatory roles that have resulted in duplication of, and sometimes conflicting, activities across institutions (Karisa, 2010). In the worst cases, the riparian zone policy created tensions between residents and implementing agencies, it resulted in significant protest and proved unenforceable (AIP, 2009). Many policymakers and practitioners have recommended that governments look for ways to work more closely with communities, in recognition of the fact that historical “top-down” approaches have failed. A number of respondents identified the need for a more nuanced understanding of flood extents and housing patterns to allow for responsive and cost-effective plans for adaptation interventions and re-housing where necessary.

2.1 Flooding in Nairobi

Until 12th May 2015, when the city of Nairobi was brought to a near standstill by a 24 hour rainfall event, flooding in Kenya had been perceived as a predominantly rural problem. The May 2015 event highlighted the impacts of climate change and rapid urbanisation and elevated urban flood risk as a significant issue in the public consciousness in cities like Mombasa and Nairobi. In urban environments such as these, where population densities are higher, the economic costs and infrastructure losses resulting from flooding are also higher (Jha et al, 2012). As noted by respondents impunity has also affected flooding as residents from every socio-economic bracket encroach into riparian zones in the Nairobi River Basin.

These issues are expected to get worse. By 2025 Nairobi’s urban population is projected to double (KNBS, 2008), with the majority of the new arrivals expected to be housed in informal settlements. This will increase riparian encroachment and further reduce pervious surfaces throughout the city, increasing surface runoff. Climate change scenarios point to an increase in mean precipitation rates and intensity of high rainfall events in East Africa (Shongwe et al, 2011; Cook and Vizy, 2013). Nairobi experienced record rainfall and flooding in 2015 and 2016.

Although challenges and missed opportunities exist in Nairobi, there is a growing level of interest and engagement in the issues of flooding, climate and appropriate policy responses. This is clear from recent initiatives such as the Nairobi River Basin Program, the Urban Rivers Rehabilitation Programme and the Taskforce for the Rehabilitation of the Nairobi Dam as well as the evolving Stormwater Masterplan and the Nairobi 2030 plan. The severe flooding of May 2015 and the recent

El Niño period have sharpened governmental mobilisation and the recent devolution of power to the county level puts Nairobi in a favourable position to drive collaboration across relevant departments. As one of the "100 Resilient Cities" (100RC, 2017) the city has signalled an intent to work on these cross-cutting issues.

2.2 Flooding in Kibera

Kibera, the most populous informal settlement in Nairobi, covers 225 hectares adjacent to the Ngong River and its tributaries and has a population of approximately 300,000 (UN-Habitat, 2006). The Ngong River is one of three major river systems in the Nairobi River Basin, with an upstream catchment of 4,500 hectares. Immediately downstream of Kibera lies the Nairobi Dam and 5km further is Nairobi's Central Business District. Organic pollution levels driven by the unchecked disposal of solid and human waste from the settlement can be at the level of raw sewage (NRBP, 2008). The residents of Kibera face many challenges including high levels of economic poverty, high rates of crime and unemployment, and insufficient water and sanitation infrastructure.

The authors' estimate that over 22,000 people live within 30m of the Ngong River in Kibera (based on extraction of compound areas from January 2015 LiDAR and average household numbers from the 2015 survey). Every year, residents in Kibera face the risk of flooding, which causes death, disease and destruction of property. 6% of residents were forced to relocate due to flooding in the 2015 March-April-May 'long-rains'. Rents are cheaper along rivers and streams where flood risk is higher, attracting the poorest and most vulnerable residents who are willing to risk their lives and assets to stay in the city. While flooding is one specific climate-related risk in Kibera it also ties to a much broader set of vulnerability issues (waterborne disease, public health, livelihoods, urban fragility). For a recent review of flood impacts and local adaptation measures in Kibera see Mulligan et al (2016).

3. Rationale for "Building Urban Flood Resilience" Study and Modelling Process

3.1 Study Objectives and Components

The challenges introduced in Section 2 were at the basis of a two-year action-research study in 2015 and 2016 developed by a team, consisting of KDI and BuroHappold Engineering and supported by the Swiss RE Foundation entitled "Building Urban Flood Resilience: Integrating Community Perspectives".

Kibera was selected as an example of a large informal area facing significant flood and drainage challenges consistent with other settlements in Nairobi as well as in other cities. The study sought to address the following overarching needs (KDI, 2015):

1) The need to develop an approach to flood modelling and risk-mapping that is applicable in the informal context and integrates community-level information on multiple hazards and risks;

2) The need to demonstrate the validity of a broader menu of flood risk management options that focus on building social cohesion and resilience, alongside appropriate infrastructural and policy measures;

3) The need to identify and implement social resilience projects (e.g. early warning systems, flood management committees, emergency response centres) that demonstrate the low-cost, high-benefit value of these approaches;

4) The need to build the capacity of institutional stakeholders to undertake integrated flood risk management and implement flood management options in a consultative and collaborative fashion that incorporates conflict-sensitivity and the social dimensions of resilience.

The development of a hydraulic model for the Ngong River was seen as a key step towards developing an integrated approach to flood risk management in the Ngong catchment and was a fundamental task in the overall study. A conceptual framework for how the hydraulic model fits into the wider study to address some of the core issues is given in *Figure 1*. The model relates the challenges identified and the proposed solution to "the 5 characteristics of integrated flood risk management" as described in Samuels et al. (2010). The process of developing the hydraulic model is described in more detail in the remainder of this paper.

4. Hydraulic Modelling Process

4.1 Objectives

One of the key objectives of the modelling process was to develop a 'live' model (tool) that could be utilised immediately, but updated as more information became available. The model is not intended to be a flood forecasting tool, but used for design and planning purposes. It was important to create a modelling tool that produced outputs easily understood and interpreted by the local community. This would help inform design projects proposed in the area.

Therefore, at an early stage, the team defined that the strategy for the analysis should be based on an open-source and free-to-use basis. Whilst this would reduce the impact of software costs on the project budget, it was also considered that open-source and free-to-use software would maximise the potential for adoption of the approach by potential institutional partners on the project and in future initiatives.

4.2 The Flood Modelling Process

Mapping and analysis of catchment data was carried out using Quantum GIS software and the model build was carried out using 1D Flood Modeller, which is free-to-use for models with fewer than 250 computational nodes. The geographic flood model extents was defined as the Kibera settlement and surrounding neighbourhoods (2,100 ha). The total upstream catchment draining to the Nairobi dam is 4,500 hectares and upstream of Kibera consists mainly of undeveloped forested areas (the Ngong Forest). Hydraulic modelling best practice used in the UK formed the benchmark in building the model. The process of the model build is shown in *Figure 2*.

A number of context-specific challenges to developing and applying the model in the local context and are described as follows:

- *Historical rainfall and future climate change*
    - Within Nairobi and Kenya in general, there is little, if any, rainfall, flow and water level data available. This makes estimating flood flows very challenging. The most relevant and robust information found has been Intensity-Duration-Frequency curves developed by the Kenyan Ministry of Water Development (*Rainfall Frequency Atlas for Kenya, 1978*), for 48 stations within Kenya. The curves provide estimated rainfall depths for durations from 10 minutes to 24 hours and return periods up to 100 years. The Rainfall Frequency Atlas for Kenya data was compared with rainfall data from other sources and papers to assess its

suitability.

- It is anticipated that climate change will result to a wetter climate with higher intensity events in East Africa (Shongwe et al., 2011) and increased extreme wet days (Cook and Vizy, 2013). Based on a review of the available literature, potential climate change impacts were represented as a 25 % increase of rainfall depths, resulting in higher flows, flood depths and larger flood extents.

- *Establishing representative flood flow routes*
    - *Acquisition of LiDAR elevation data* – freely available 30m resolution satellite elevation data (ASTER GDEM) was used for the upstream catchment areas. For the Kibera settlement and surrounding area a 5m resolution DTM extracted from LiDAR data was procured to ensure that the flood model represented the flow routes as accurately as possible. The resolution was based on a compromise between data quality/accuracy and cost funded by the project.
    - *Acquisition of aerial photography* – to help identify how flood flow routes may be altered by structures such as culverts and roads, high-resolution photography from 2015 was used. This also aided the process of delineating and verifying the catchment watershed boundaries.

- *Appropriate representation of hydraulic structures*
    - KDI field staff surveyed 64 key hydraulic structures and obstructions along the main watercourses of Kibera and classified, dimensioned, photographed and geo-referenced using handheld Android devices and the Open Data Kit application. This enabled rapid and accurate recording of location and dimensions of structures.

- *Appropriate representation of watercourse channel profiles*
    - KDI field staff together with volunteers from Engineers Without Borders UK surveyed river cross-sections using an engineering level at five site locations through the 2015 'long-rain' season. The sites were chosen based on relevance for information to the model, ease of access and safety.

- *Verification against historical flood information and community data*
    - In May 2016 KDI ran workshops with residents in the Andolo area (a high-exposure area) where participants were given aerial maps to identify specific common areas and locations and subsequently the extents of historical events. These were overlaid with the flood extents generated from the model to verify the accuracy/overlap of the model and local information, and to raise awareness of flood-risk in the area (see ***Figure 3***).

- *Model calibration*
    - Local community operatives were trained by KDI staff to record water level measurements at the cross section locations, during and after the 2015 'long-rain' events. The cross-sectional surveys and river level measurements were subsequently used to calibrate the flood-model and also check that the topography of the river that's being generated from the remote sensing data is consistent with what is being measured at a finer level of detail on the ground.
    - Storm drainage network information and potential surface water flood flow

routes were not included in the model. However, surface water flooding is a known issue and therefore this limitation had to be clearly communicated to stakeholders when presenting the results, as a caveat in the flood extents mapping for consideration in any detailed planning, and in any community awareness programs.

The outputs of the model are discussed in the following section.

5. Outputs, Application and Hand Over

5.1 Model Outputs - Flood Depths and Extents

The 1D Flood Modeller software simulates the several input storm scenarios and produces outputs at all cross section locations. The model calculates the flood flow, stage (level of water), and velocity at the centre of the channel for each cross-section and interpolates between the sections, approximately every 100m. The stage information was used in conjunction with the LiDAR topographic surface to estimate flood depths and create flood depth and flood extent maps, as shown in ***Figure 4***.

The 'live' nature of the model enables constant refinement and calibration to represent localities more accurately, as more data becomes available. Model interrogation and refinement can be carried out in locations of interest as was performed in the Pilot projects described below.

The potential impacts of an extreme 'not-experienced in a lifetime' flood event were assessed by modelling the 1 in 100 year flood event (the event that has a 1% probability of occurrence in any given year). Climate change was included as described earlier in the paper, and the resulting flood extents were illustrated as an overlay to the aerial photography of Kibera. Similarly, more frequent events such as the 1 in 25 year flood event were also illustrated with the intention to be compared with extents of impact areas from recent floods.

The flood extent maps have been prepared at a range of scales to support stakeholder consultations, major and minor infrastructure planning as well as detailed design.

5.2 Model Outputs - Overlay of Community Risk Data

Overlaying the household level data with the flood extent information produces a broader understanding of a range of risks and allows for linkages to be identified between flood exposure and impact, as well as to socio-economic and demographic issues. For example, the flood extents and survey information revealed the correlation between severe flood risk and other issues in the Andolo community. Here the highest reported household flooding (59% of households were flooded in the 2015 ‘long-rains’) corresponds with the lowest residency (3.8 years average per household), the cheapest rents in the settlement (1,800 average Kes/month) and related rates of crime, insecurity, and limited social cohesion and social contract. Rates of diarrhoea in children under 5 in the previous 2 weeks is at 28% (from June 2015), twice the national urban average from the latest DHS survey. Overlay of flood extents data with household level data is shown in ***Figure 5***.

5.3 Proposed Applications

One key objective of the model build and development, was to produce a tool that could be used by different local stakeholders. An essential element in meeting this objective was the preparation of handover document in early 2017 which is intended to enable the use of the model by a range of potential users, tiered in 4 levels:

I. **Community users** such as local communities, CBOs, NGOs, humanitarian organisations who will have the ability to interpret the flood extent maps to inform local community projects and develop flood awareness and preparedness;
II. **County Government** users who support implementation of a variety of scale of projects at a local level;
III. **National Users** such as national ministries who support scaling out (and up) of the model through policy development and adoption. These users will have a good understanding of model assumptions and hold instructions for model modifications;
IV. **The Research Community** (such as universities and research centres) who could enhance and improve the capabilities of the tool according to changing demands and conditions,.

Final hand over documentation was produced in early 2017 though significant elements were tested in 2016 through the applications described in the following sections.

5.4 Application in Planning, Design and Construction

Pilot Projects

In 2015 and 2016, the KDI field team used the flood extent maps combined with the household survey data to identify areas vulnerable and prone to flooding. Two areas were identified in November 2015 as potential sites for pilot project interventions funded under the program: Andolo neighbourhood and Gifted Hands School. The intention of these pilot projects was to demonstrate the use and applicability of the model in a real project development process. Considerations in selecting the areas included choosing projects that would be most impactful in terms of targeting high-exposure areas as well as communicating the value of the technical (modelling) and community-based approach of project development. Further detail on the projects selected and developed and how the model was used in each is given below.

Pilot Project 1 – Andolo neighbourhood

The first project was in one of the consultation areas which has proved particularity vulnerable and prone to flooding – the Andolo area of Lindi Village just 300m upstream of the Nairobi Dam. Andolo is perhaps the most vulnerable area in Kibera as detailed in Section 5.2. Many of the households in Andolo are located within the 1 in 100 year flood extents as well as the government-designated 30m riparian zone. The flood maps shown in ***Figure 6*** were used to identify how the proposed area for development could be affected by extreme flood events.

As a result of using the maps, the following actions were made possible:

- *Local model refinement* - Site surveys close to the location of interest involved inspection of upstream and downstream structures and identification of drainage paths to the river and its tributaries. This information was then interpreted and adjusted in the model to represent the local hydraulic characteristics more accurately.
- *Validation of the model* - Flood extent maps for the 1 in 25 year flood event were compared both with flood extent information provided by local residents, as well as debris or repair work marks on the household walls following the recent flood event in May 2015 (estimated to be in the order of 1 in 20 year event). The modelled flood extents provided a good comparison with the May 2015 extents, adding confidence to the use of the model to predict extents for higher order flood events.

- *Understanding the design life flood risk (extreme event)* - the map showing the 1 in 100 year flood event (including allowance for climate change) indicated that the entire site is potentially at risk from flooding in the future to depths between 0.2m up to 2m.
- *Recommendations for allocation of appropriate uses within the development site* - ensuring that uses that could pose a contamination risk to the river or be detrimentally affected by flood flows were avoided.

Through community workshops performed by KDI and EWB-UK volunteers in summer of 2016 a drainage and access project was developed and implemented in the autumn of 2016 using the flood risk information developed from the model.

Pilot Project 2 – Gifted Hands School

The existing Gifted Hands School in Gatwekera area of Kibera lies on one of the major tributaries to River Ngong. The site suffers from the combined effect of fluvial flooding on its low lying edge and pluvial flooding from upstream catchment flows crossing through the site and ponding in local depressions. The large open spaces that exist in this site provide an opportunity for Sustainable Drainage System development and showcasing as a demonstration project.

The flood map extents were used to enable masterplan development at the Gifted Hands Productive Learning Space.

- *Validation of the model* - Water level measurements from the river were taken during March-May 2016 (estimated to be in the order of the 1 in 17 year event) and compared with flood model depths for the 1 in 25 year event.
- *Constraints mapping* - The extents have been mapped on a constraints base map of the site, used during community design workshops to enable community and Design team understanding of the site and its surroundings (see ***Figure 7)***.
- *Land vulnerability* - Land allocation for the school masterplan has taken into consideration the potential flood extents from the adjacent tributary as well as the government-designated buffer zone. Open green spaces and playing areas are proposed at the low lying areas whereas vulnerable uses such as classrooms, kitchen and dining areas have been placed further away and at higher elevations.

The model simulation of different flood events highlighted that the flood risk to the site is reduced by the upstream railway embankment and culvert which restricts fluvial flood flows adjacent to the site. This provided increased understanding of the fluvial flood mechanism at the site. This demonstrated that the main flood risk to the site is from surface water and therefore enabled communication for strategies focused on surface water flood mitigation.

5.5 Other Applications - Public Infrastructure Planning

Through KDI's ongoing work with local authorities in Kibera, in particular, the Nairobi County Council (NCC) Department of Roads and Public Works, there have been multiple opportunities to apply the flood model in various planning exercises in 2016. These included the planning stages of the design of a new road planned to pass through Kibera and over the Ngong River and the assessment of the reasons behind the surcharging of a new public sewer line through Kibera. The flood mapping can be seen to be an effective advocacy tool to allow consideration of flood risk not previously possible. Flood extent information was readily understood at the various governmental levels from both political and technical staff suggesting this is a good format for working with municipal partners. It is notable that this type of analysis has not been produced previously in the planning of major development or infrastructure, whether in the form or preexisting flood maps, or in the development of flood risk assessments for the specific projects.

6. Learning and Further Application

6.1 Benefits of a 'live' model

By creating a hydraulic flood model that could be adopted by the relevant stakeholders, the model can be updated to meet the needs of the specific user. The following outlines examples of some of the potential ways the model can be manipulated:

- Local design initiatives – although the model was designed to give an overview of the flood risk at the settlement scale, using a 5m elevation resolution, if more detailed topographic information is available at identified sites for potential development, this information can be incorporated into the model and run.
- Government planning – by adopting and maintaining a model that incorporates new structures, changes to land use and updates in available hydrological data, the model can be considered as 'cumulative', always up-to-date and assessing the current situation. This helps for planning purposes and is particularly important for settlements such as Kibera where tenants can consistently reclaim land within the riparian zone, and where authorities may be required to displace residents to build large scale infrastructure projects.

6.2 Challenges of a 'live' model

There are three main challenges envisaged with handing over the hydraulic model and its results:

i) the modelled flood extents are taken as absolute areas of flood risk, without considering the impact of other sources of flooding, such as overland surface water flood routes;

ii) the model could be adopted by different parties and updated at different times by different people. This can prevent appropriate tracking of the model and effective maintenance and QA, potentially making it redundant in the future;

iii) if inexperienced stakeholders use the model, they may interpret the results incorrectly or not update a particular parameter when making a change to another.

These are just some of the challenges identified at this stage; more may become evident over time. To overcome some of these, it is proposed in this instance that KDI, based in Nairobi, become the custodians (gatekeeper) of the model. In this way its distribution can be monitored and tracked appropriately.

6.3 Transferability and Scaling

The process has shown potential for application in other informal areas in Nairobi. Working closely with the Nairobi City County in the development of this project has shown its value as an entry point for macro planning discussions on identifying risk. Often the lack of data and access to the informal areas for County officials means the first questions are often around identifying "hotspots", areas of high exposure and risk, to people and infrastructure. The level of resolution of the 1D model is appropriate for identifying these areas and starting a conversation with County officials around potential interventions.

In terms of model development perhaps the greatest challenge as compared to a “conventional” modeling process is the collection of field data. Though the government partners on the project were able to interpret and use the outputs of the flood extents maps they were less conversant in local risk data collection which is critical to improving government engagement and the responsiveness of programs. This requires a local partner with access and legitimacy in the targeted communities.

One constraint for transferring the process could be the cost of high quality remote sending data to enable detailed modelling. Further analysis is required to understand the difference in results provided between the LiDAR (purchased) and ASTER-GDEM (freely available) satellite data to understand the impact of the different resolution data. Following this study, a case could be put forward to different institutions for the need for funding for high resolution data at an early stage in a project, if found to be important.

7. Conclusions

Flooding occurs several times a year in many informal settlements, interrupting economic activity, contaminating water supply, leading to disease outbreaks, destroying the limited assets of poor households and often displacing residents (Douglas et al, 2008). With the projected growth of low-income areas in African cities (United Nations, 2014) and climate change projections for extreme rainfall events (IPCC, 2014) these issues will continue to grow and be of pressing concern to residents and city authorities.

The work touches directly upon several key “gaps in evidence” identified by IIED (2013) in particular: “How can local knowledge be used alongside scientific data to help shape city decisions in planning for risk reduction and disaster preparedness?”. Providing easy to develop and use flood risk modelling is one practical step to quantify and characterise the scale and spatial distribution of risk. Engaging residents in data collection related to model development and in discussion of the results with relation to historical events raises awareness of flood risk locally and may lead to behaviour change. Flood maps are also useful in engaging local and regional authorities in local flooding challenges and in providing an entry point for discussing issues in low-income areas. The overlay of community level data can be a powerful advocacy tool in communicating the linkages between flooding and a broad range of public health and livelihoods impacts.

At the same time the process raises questions on who and how this process could be developed in the future in similar contexts. Local authorities would ideally be able to develop and apply similar types of tools internally, or to be able to better scope services to engage local consultants to produce similar tools or assessments, to ensure ownership and control over the process, and to align more directly to government implemented development initiatives.

Through the process we find evidence that community-involvement in data collection can enable closer community engagement and understanding of proposed interventions. To enable field data collection and improved participation a well-trusted intermediary may be required in certain areas to close the gap between formal city processes and the informal neighbourhoods. It is hoped that the partnership between engineers, civil society organisations and local authorities demonstrated by this project can be encouraging and instructive for more integrated and responsive practices in Nairobi as well as in other cities in Kenya.

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Figure Captions:

Figure 1: Conceptual framework of Integrated Flood Risk Management in the Kibera context and project response

Figure 2: The hydraulic modelling process

Figure 3: Workshop in Andolo neighbourhood to check flood extents and household survey data against historical flood information

Figure 4: Flood depth map for the 1 in 100 year event including 25% allowance for climate change. Existing structures such as bridges and culverts along the tributary are also marked on the map.

Figure 5: Flood extents overlay with reported flooding from post-rains household survey.

Figure 6: Andolo site development boundary and flood extents for 1 in 25 and 1 in 100 year plus Climate Change scenarios.

Figure 7: Left - Flood depths for the 1 in 25 year event (similar to the May 2015 event). Right - Flood depths for the 1 in 100 year event including 25% allowance for climate change (Design Flood Event)