A methodological approach to measure interrelations between urban form and flood-related risks in Kampala, Uganda

Tjark GALL, Urban Framework, Germany

Keywords: Urban form, Climate Change Risk, Spatial Equity

This paper[i] aims to examine the interrelations of spatial characteristics to the often-unjust distribution of climate change risk and vulnerabilities and develop a methodological approach for Kampala to redress this situation. The research intends to increase the understanding of spatial equity and proposes a method to quantify it in environments of limited preceding research and data availability to support better-informed policy and spatial intervention strategies.

1. Introduction

Fifty per cent of the world population is already living in cities. By 2050, it is expected, that more than two-thirds will live in urban settlements. The growth will mostly occur in African countries where one billion people live at present. More than four billion people are expected to live in Africa by the end of the century and thus make up more than one-third of the world's population (United Nations 2015).

This rapid growth steadily increases the importance of sustainability in urban planning while it also contributes to rising spatial injustice, mostly in sub-Saharan Africa (SSA). Access to land, services, employment opportunities and therefore also the city itself vary strongly between different income and social groups (Parnell and Walawage 2010). These gaps are significant and disadvantage the already most vulnerable groups even more, specifically under the increasing threat of climate change and its accompanying risks. The understanding thereof as well as realising which factors positively or negatively influence spatial equity is crucial for tackling these inequalities.

This paper analyses the specific situation in the capital of Uganda, Kampala, and the distribution of flood-related urban risks to investigate this spatial injustice, as well as its driving forces and consequences. It results in a methodology which attempts to establish a relationship between internal and external spatial characteristics of settlements and their correlation with the level of spatial equity within. Answering the following research questions is central to the study:

- How can the quantification of risk exposure, adaptive capacity and sensitivity can be simplified and carried out at small-scale spatial resolutions and locations with limited data?
- Which spatial characteristics of urban form are measurable with restricted spatial data and correlate with social vulnerability?

The objective is to expand the existing literature by applying it to the dynamic context of urban Uganda. Additionally, existing approaches, as well as newly developed methods are integrated by retrieving various spatial indicators from GIS data/aerial photos and relating them to statistical data (e.g., vulnerability, socio-economic profiles) and qualitative results of household studies. The anticipated outcome of the research is an improved understanding of urban dynamics, justice, and accessibility, specifically in the context of Kampala, and to build a better basis for informed policy decisions, as well as spatial interventions. Even if the methodology is context-specific, generalisations can be made for other urban areas in sub-Saharan Africa and assist in the quantification of socio-spatial inequalities in the field of climate change.

2. Background

The global population continues to increase rapidly and is mostly concentrated in the urban areas of the global south. More specifically, the African continent is experiencing the highest population rise in the present century. Adding to the pressure on cities by more residents and spatial expansion, climate change further stresses these urban systems. Cities became the centre of the current development and sustainability debates. Their importance is widely acknowledged and continuously highlighted by international and national institutions around the world, representing a central aspect in the Sustainable Development Goals (SDGs) of the United Nations. SDG 11 focuses on making "cities and human settlements inclusive, safe, resilient and sustainable" while the city itself functions as the arena for achieving nearly all the other goals (UN 2015, p. 14).

The questions arise, what this development will mean for the population within cities and how it can be managed and steered into a sustainable direction. The report 'Our common future' already highlighted spatial injustice in 1987, together with the necessity to identify the most vulnerable groups and tackle the social and environmental risks which accompany the population surge (WCED). However, more than three decades went by, and even if sustainability is a primary concern nowadays, more people than ever before are living in risk-prone circumstances, and environmental depletion does not slow down either (Adger 2006; Brecht et al. 2013; UN-Habitat 2014; UN 2015 & 2016).

With urban areas as the primary habitat of the world's population, fast urbanisation patterns in sub-Saharan Africa (SSA) increase the demographic pressure, while climate change stresses the cities, and their adaptation is challenging because the responsible institutions often lack resources and capacity to tackle the rising complexity and quantity of issues (Pieterse and Parnell 2010; Myers 2016). In 'Africa's Urban Revolution', Parnell and Pieterse emphasise the general growth which occurs in both urban and rural areas but its strong concentration in urban agglomerations. This development is not only about the increase of the number of residents but comes along with "severe overcrowding, lack of sanitation, constant threat of bodily harm and abuse" and is "linked to the structural poverty and systemic exclusion experienced by a large proportion of the urban population in most African cities". Unequally distributed pressures on age, income and gender groups result in negative externalities on health, productivity and economic behaviour (Pieterse and Parnell 2010; Bartlett 2008; Fainstein 2010). Furthermore, climate change and global environmental change are leading to more rural-urban and/or trans-national migration of climate refugees, unequal distribution of land, hazard risks for settlements in the shape of floods, landslides, droughts or heat waves, to just name a few which highlights the "dynamic processes and the interplay" of these elements (Parnell and Walawage 2010).

However, inequality does not only exist amongst different social groups within the cities but also on the global scale. Climate change itself is a global challenge, mainly induced by the industrialised countries while the most impoverished countries contributed the least but suffer the most from its consequences (Althor et al. 2016). The suffering is further intensified due to a widespread lack of adaptive capacity, meaning the "potential, capability, or ability of a system to adapt to climate change stimuli or their effects or impacts" (IPCC 2001).

Parnell and Walawage (2010) further stress the importance in these complex circumstances of creating the capacity to ensure urban resilience so that the livelihood of everyone in the city is not negatively affected by the broader global demographic and environmental processes. Another important aspect is the interplay between the social and ecological systems and their cultural understanding which varies fundamentally between the western and most societies in SSA. While the dominant western notion sees them as separate entities, in most SSA cultures nature and society are interwoven. The consequences of the development in industrialised nations lead to the destruction of locally much higher valued ecosystems, while differing perceptions result in complications in cooperation, the transfer of 'knowledge' and coping mechanisms (Myers 2016).

All these issues emphasise the plethora of challenges which cities in SSA are facing. Tackling them will be one of the critical tasks for policy makers and planners of the coming decades. Starting with the predominant injustice and its spatiality in urban agglomerations, this research tries to contribute to the understanding thereof by looking at ways to quantify the interrelation between urban form and social vulnerability with a focus on risk exposure and adaptive capacity. UN-Habitat (2014) called the development in SSA cities an "urbanisation of poverty". This led to plenty of unplanned and underserviced settlements with fundamental and increasing material injustice and lack of opportunities between them and their affluent neighbourhoods. Understanding these different settlements patterns and their integration in the urban fabric will be the core of the analysis of urban form, while the varying level and types of risk exposure and the interdependence between social variables and adaptive capacity will serve as comparative values.

Urban form, defined by Williams as "the physical characteristics that make up built-up areas, including the shape, size, density and configuration of settlements" (2014, p. 6) is moving towards the centre of interest in the sustainability debate, while its importance on the social and ecological risk exposure is further emphasised (Jabareen 2006; Hillier 2009; Louf and Barthelemy 2014; Fragkias et al. 2013; Oliveira et al. 2014; Pelling and Wisner 2009 and others). Myers adds to the definition of urban form, in his words *cityshape*, that in the context of SSA it is the physical as well as the "socially and culturally produced environment" (2016, p. 19), highlighting non-spatial characteristics. Jane Jacobs already described the strong interrelation between the built environment and social dynamics of cities in 'The death and life of great American cities' (1961), where she states that cities should be a place for people, even if that is often not the case (anymore). Building upon Jacobs' perspective, Gehl (2010) further embraces the interconnection of urban form and social life, sustainability and health through variables of density, compactness, and diversity while also highlighting its relation to risk (e.g., traffic accidents, robbery). Additionally, he argues that high-quality urban space can fuel interaction and social inclusion, and therefore a higher sense of community which again can lead to better cooperation and assistance in case of disaster regardless of their type or scale. He also states the importance of shared urban space since overpopulation and rising poverty put pressure on the livelihood of people (Gehl 2010). Jacobs continues to describe the impact of being better interconnected on adaptive capacity, further supporting the interrelation between the spatial and social dynamics of cities.

The issue of justice in cities, in which context this research is situated, was famously put into focus by Susan Fainstein in 'Just Cities'. She gives a broad overview of different notions of justice, how it can be conceptualised and quantified and also states that injustice rises and the poor, mostly women and children, represent the most vulnerable groups (2010). This link between poverty and vulnerability in the field of environmental risks was further studied by UN-Habitat (2014), naming the lack of decision-making power and resources, mostly in time of disasters, as the primary reasons. They also emphasise the disproportionate distribution of risk exposure among different age and gender groups (see also Bartlett 2008).

What do urban risks or vulnerability mean and what do they encompass? Brooks (2003) distinguishes generally between social and biophysical vulnerability. Social vulnerability includes everything related to the human and is the focus of this research, while biophysical vulnerability focuses on the ecosystem and biophysical environment. Risk, on the other hand, is normally composed of different types of hazards, their occurrence and scale, but has numerous definitions which are further discussed below. The last two aspects are adaptive capacity as the "potential, capability, or ability of a system to adapt to climate stimuli or their effects or impacts (IPCC 2001, p. 881) and sensitivity as "how affected a system is after being exposed to the stress" (Engle 2011, p. 649, compare to Adger 2006 and IPCC 2001).

The proposed methodology in the case study of Kampala aims to measure the key elements – urban form, climate change related risk exposure, adaptive capacity and sensitivity – with a view to understanding their interplay in the context of socio-spatial justice as shaping elements of urbanisation and livelihoods. The example of Kampala provides a compelling case, due to its fast urbanisation and current as well as predicted spatial expansion but early development stage in comparison with other Eastern African cities (Karolien et al. 2012; UN-Habitat 2014). At the same time, it experiences severe climate change-related consequences, and has high levels of informality, low levels of land tenure security and building regulations, basic service provision and faces institutional challenges which further complicate the situation (Karolien et al. 2012; Nyakaana et al. 2008; Insunju 2016; Richmond et al. 2018; UN-Habitat 2014). Therefore, it is an interesting case study to analyse itself while its comparability to many other cities in SSA provides the opportunity to transfer and apply the same approach in other geographical contexts.

2.1 Urban form

The first central concept is urban form. It can mainly be conceptualised as the built embodiment of urban society, generally divided in macro, meso- and micro-scale (city, settlement/neighbourhood, building) and is constituted by different layers, including street networks, build environment, and land use/division (Pont and Haupt 2009; Oliveira 2016; Hillier 2009). Two different levels of urban form are distinguished to measure urban form. Firstly, the city level (macro scale) includes the demarcation of the urban agglomeration and is necessary to understand larger interrelations, e.g. the accessibility to the economic centres or differences between core and peripheral areas. The second level is the settlement area (including both meso- and micro-scale), which looks more at the built environment and includes built density, space allocations, proximities, or the density of street intersection. The measurable characteristics of the latter are divided into the three layers. There are various claims about the interrelations of urban form and sustainability. For example, they state that smaller or denser more interconnected cities might be more sustainable (see for example Adolphe 2001, Oliveira 2014, Jabareen 2006, Fragkias et al. 2013; Dave 2010; Louf 2014). The latter would be interesting to analyse in Kampala, but this would require partly non-available data. Also, due to the overall performance of cities as systems (i.e. emission, GDP) they would only produce compelling results if compared with other cities.

2.2 Social vulnerability

The second central concept is social vulnerability. There are countless definitions of vulnerability and its constituting parts, mainly depending on the time, context and background of academic research. Therefore, it is crucial to define the various parts of social vulnerability and conceptualise them in a coherent and commonly agreed upon manner. To start with, vulnerability is conceptualised in a broader context than either "the amount of (potential) damage caused to a system by a particular climate-related event or hazard" or as the "state that exists within a system before it encounters a hazard event" (Jones and Boer 2003 and Allen 2003 in Brooks 2003). Currently, the most accepted definition follows the latter. Furthermore, a distinction between different types of vulnerability can be made, even if there is no consensus on the actual separations or terminology. The most common types which can be found in the context of urban climate change vulnerability are social (also referred to as human) and biophysical (or natural) vulnerability. However, various studies also examine, for example, economic or institutional vulnerability (Brooks 2003). Vulnerability, in general, is defined by Adger (2006), building upon the definition of the Intergovernmental Panel on Climate Change (IPCC) as the "state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence to adapt". In the case of social vulnerability, the system which is vulnerable encompasses all socially connected elements, while biophysical vulnerability can be defined as the vulnerability of the natural environment to climate change-related stressors. A quick overview of the definitions of the constituting elements (Table 1) is provided, together with a diagram showing its connections (Fig. 1).

Hazard	While there are also different types of hazards, the focus here is on natural hazards, which can be defined as "physical manifestations of climatic variability or change" (Brooks 2003, p. 3). The primary natural hazards are cyclones, floods, earthquakes and landslides (Adger 2006; Brecht 2013).
(Hazard) event	A hazard describes the initial stressor / physical manifestation of climate change, while an event is the more precise occurrence of a hazard which takes the exposure of the system into account (Adger 2006; Brecht 2013).
Disaster	A disaster takes the probability into account and further incorporates the consequences of events of natural hazards (Adger 2007; GIZ 2014).
Risk	The combined outcome of exposure, the sensitivity of a system and its adaptive capacity. As higher the vulnerability in general or risk exposure and sensitivity, as higher the risk. As stronger the adaptive capacity, as lower the risk (Adger 2007; Cardona et al. 2012; Dickson et al. 2012; Brecht 2013; GIZ 2014; Pelling 2016).
Risk exposure	"Character, magnitude, and rate of change and variation in the climate. Typical exposure factors include temperature, precipitation, evapotranspiration and climatic water balance, as well as extreme events such as heavy rain and meteorological drought" (GIZ 2014, p. 21).
Adaptive capacity	No generally applicable definition exists, as the adaptive capacity dependent heavily on the type of hazard, environment, and system which is looked at. However, often constituting or influencing elements are generally resources, knowledge, institutions, and the economy (Adger 2006; Adger 2007; GIZ 2014).
Sensitivity	"Degree to which a system is adversely or beneficially affected by a given climate change exposure […and] shaped by natural and/or physical attributes of the system including topography, the capacity of different soil types to resist erosion, land cover type. But it also refers to human activities which affect the physical constitution of a system" (GIZ 2014, p. 21).

Table 1: Definitions of social vulnerability elements

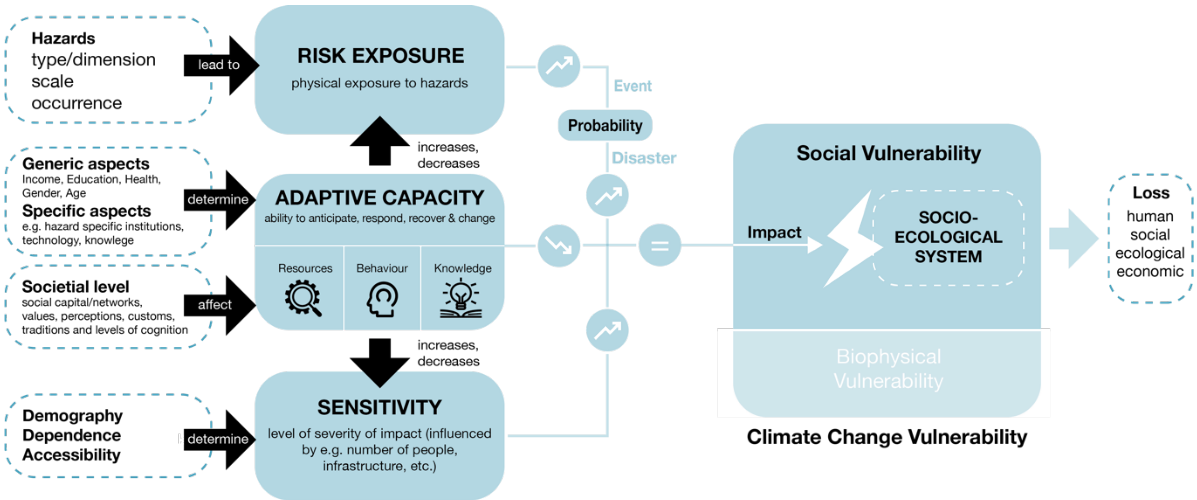

Figure 1: Conceptualisation of vulnerability and its connections (Author 2018)

2.3 Flood-related risks in Kampala

The focus of this research is on Kampala, the capital of Uganda. While it is the second least urbanised country in Eastern Africa (2011: 31.2%; UN-Habitat 2014, pp. 147-150), the urbanisation rate is significant in comparison to other countries in sub-Saharan Africa, and even more at a global level. These developments lead to an assumed current urban population of Kampala of somewhere between 1.6 and 2 million (1.66 m in 2011) and predictions of about 100,000 new urban inhabitants which lead to an expected population of 3.5 m by 2025 (UN-Habitat 2014). This high urbanisation rate leads to a sprawling urban agglomeration even outside the jurisdictional boundary of the Kampala Capital City Authority and furthermore to densification and (formal as well as 'informal') infill in areas which are either due to their soil texture and/or proximity to flooding areas, not suitable for residential areas (Karolien et al. 2012; Nyakaana et al. 2008).

In 2009 only 9.1 % of the national population was living below the poverty line, one of the lowest in Eastern Africa (UN-Habitat 2014). However, the countrywide number of people who are living in self-planned settlements increased from 1.5 m in 1990 to 2.5 m in 2007 (UN-Habitat 2014). These self-planned settlements are often experiencing the most severe livelihood challenges, are situated in inappropriate and inaccessible locations and lack access to basic services and critical infrastructure (UN-Habitat 2007). Nyakaana et al. (2008) furthermore point out that growth brings about a "lack of infrastructure, social services and poses planning and environmental problems" and emphasise the interrelationships between population, development and environmental issues (UN-Habitat 2014). While the Kampala Structure Plan was prepared in 1972 and mainly implemented, it catered essentially for the European and Asian residential and economic areas and did not consider the less privileged society. A revised plan from 1994 tried to cope with these arising challenges but was only partly realised and let to the evolution of more self-planned settlements without much institutional steering (UN-Habitat 2007, pp. 9-10).

The Poverty Probability Index was applied amongst others in Uganda with a globally standardised assessment method and highlights the comparatively high national poverty while pointing out the missing overall access to facilities as well as basic sanitary instalments (Schreiner 2012a, Richmond 2018). It also shows the unequal distribution of poverty over age, with an intense concentration in the age groups under 29 (Schreiner 2012b, detailed in Cannon et al. 2014). A more in-depth study of the most marginalised groups (street children, 'squatters', 'slum' dwellers) further stresses various deficiencies and challenges sorted according to their significance: flooding and infrastructure access; pollution; health issues (mainly related to the aforementioned); sanitary facilities; and social networks (Dimanin 2102). These rising pressures on the urban population of Kampala are strongly linked to the increasing climate change impacts Uganda is experiencing (MoGLSD 2017; Mabasi 2009). While the climate of Uganda always led to floods and droughts in the past with accompanying consequences for livelihoods, infrastructure and the economy, recent changes intensify these pressures. The average temperature of Uganda is expected to rise by 1.5 °C until 2027 and up to 4.3 °C until the 2080s. More frequent and extreme rainfalls are projected as well. However, they are more difficult to quantify. While the rising temperatures will have substantial effects on "water resources, food security, natural resource management, human health, settlement and infrastructure" and lead to more heat waves (MoGLSD 2017, p. 12), the rising rainfalls will result in even more flooding events which will be simultaneously more severe.

The occurrence of a variety of disasters increased in the last decades in the whole of Eastern Africa (UN-Habitat 2014, pp. 160-162). Osuteye et al. (2017) attempted to compare the number and severity in countries of sub-Saharan Africa and counted 14 natural disasters in Uganda between 2010 and 2015 which led to over 700 deaths and affected more than 1 million people. While these numbers are higher in several other countries, Uganda has a comparatively low overall population which leads to 1 in 40 of the national population being affected by disasters. These statistics show the significance of natural disasters and the tremendous effect they have on lives and national development in general. Furthermore, they compare different types of events and how many houses were destroyed or damaged. In the case of Uganda, floods (5,595), hailstorms (1,786) and landslides (1,663) are by far the highest numbers (Osuteye et al., p. 26). While hailstorms can barely be avoided and only dealt with through better adaptation, the severity of floods and landslides is largely influenced by the infrastructure, spatial location and built environment, which will be further discussed below.

UN-Habitat prepared two expansive vulnerability assessments of Kampala (2009 and 2011) in which they highlight floods and related risks as the primary stressors, but also analyse which factors contribute to the severity of, and sensitivity to disasters. They point out the importance of better and more detailed vulnerability assessments and how they increase understanding and thereby permit better adaptation measures. In the second assessment, more detailed measurements and spatial distributions of vulnerability were undertaken which led to a country-wide and Kampala-specific scoring. While this method cannot thoroughly assess and predict the vulnerability to future disasters, it provides a good overview of how and where people are most affected. The compound vulnerability score is constituted of descriptive information like the elevation and slope of the environment, combined with climate prediction data (rainfall, sea level changes) and are overlaid with the population and infrastructure (roads, hospitals, schools, health facilities) at risk (UN-Habitat 2011).

This confirms that from experience flood-related risks prove to be the highest challenge for Kampala and are, therefore, the focus of this study (Fig. 2). The direct risks include the destruction of property due to flooding, as well as landslides as results of heavy rains and more spatially concentrated floods. The secondary effects are more difficult to assess but include rising water-spread diseases (Malaria, Dysentery, Cholera), pollution due to inadequate waste management (Mukama et al. 2016) and its distribution during floods and resulting challenges after the destruction of critical infrastructure or the temporal inaccessibility (KCCA 2016).

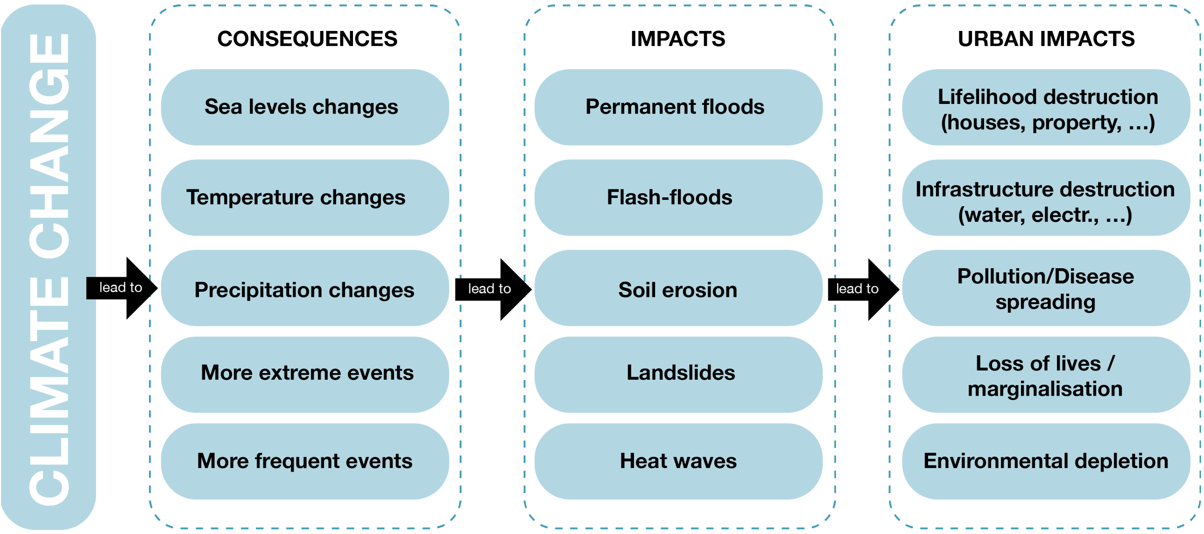

Figure 2: Climate Change impacts on urban Kampala (Author 2018)

Why are so many people living in areas which are affected by these disasters? Isunju et al. 2015 blame the overall population growth and rural-urban migration in combination with unclear boundaries and land-ownership, as well as the "long-term failure of government regimes to enforce development control" (p. 276) which led to a large number of people encroaching on wetlands. In a study of several of these affected communities, Isunju et al. found that over 55 % were female and over two thirds 30 years and younger, which again shows the unequal exposure to disaster risks. Additionally, the majority (73.3 %) of the surveyed households were only earning between 40 and 120 USD (assumed conversion rate of 1 USD = 2,500 UGX in 2015) and nearly half without secondary education. Furthermore, the perception of vulnerability to hazards was enumerated and shows that more than 50 per cent perceive themselves as very vulnerable to disease vectors and floods (Isunju et al. 2015; Isunju 2016). Lastly, there is a risk of floods negatively affecting the water quality of both tap water and even more well water which, combined with the rising water shortages endanger the water provision for the (mostly poor) population while contributing to the spread of diseases due to poisoned water and less preventive sanitary actions in times of clean water scarcity (Godfrey et al. 2003).

While a strong interrelation between the risk exposure to floods and the socio-economic characteristics of the affected population seems to exist, proving it requires an improved method to distinguish the flood-prone areas – an endeavour which is always challenging in environments of less detailed databases and due to its predictive character. Different approaches have been developed and applied to model run-off water and the effects of land use changes on the Murchison Bay Catchment area (catchment area of Lake Victoria incorporating most of central Kampala). However, limitations of the underlying data and spatial inaccuracies make them only attractive as a basis but insufficient to produce a more comprehensive representation (Fura 2013; Anaba et al. 2017). Therefore, the most promising approach is currently the overlay of three layers, including the elevation and slope of the topographical, its distance to the next flood-prone area as distinguished by the Municipality and the soil type.

3. Methodology

In order to measure and compare the various elements mentioned above, they are translated into concepts, variables and indicators (Table 2). The four main concepts of urban form, risk exposure, adaptive capacity and sensitivity are subdivided into several variables whose definitions are included in the operationalisation table. Each of these variables is further divided into one or several measurable indicators. These indicators are further defined by the following attributes[ii]:

The measurement level (1) is generally divided into two groups because the jurisdictional boundaries do not represent spatial-functional relationships. Therefore, the Greater Kampala Metropolitan Area (GKMA) and the Selected Areas (SA) are studied with two different grid sizes of 500 x 500 m and 100 x 100 m respectively. These were chosen for the study on city and neighbourhood level. The 500 x 500-meter grid spans over the whole populated area of the GKMA. The 100 x 100-meter grid is used for the in-depth study of the SA. Both cell-sizes are chosen to establish a balance between large enough cells to guarantee a certain level of representativeness while still being small enough to distinguish high-resolution differences in the urban fabric.

Another indicator attribute is the unit (2) which represents the type of the final value and forms the basis for the ensuing normalisation. The indicator type (3) distinguishes between descriptive and performance indicators. Descriptive indicators describe a certain situation without giving any indication about a negative or positive impact on the overall score, while the value of the performance indicators has either a positive or negative impact. The shown distinction is based on the literature; however, the expert interviews attempt to give a more locally-adapted understanding and can lead to minor changes of the categorisation.

Limitations of the current methodology are the risk modelling. A more advanced risk modelling method would result in more elaborated findings and could bring more differentiated interrelations to light. Lastly, due to broad conceptualisations of adaptive capacity, indicators which better describe the social networks or available resources and access to information could further enhance the comprehensiveness. However, this would require an in-depth study of the studied households through a specialised household survey which could not be conducted as part of this research. While the variety of selected and measurable indicators should be able to draw a comprehensive picture of the actual situation, these limitations need to be considered and provide a potential for further studies when more information is available.

CONCEPTS	VARIABLES	INDICATORS	INDICATOR SOURCE
1 URBAN FORM	1.1 Street Network	Centrality	Hillier 2009; Patterson 2016
		Integration (Space Syntax)	Hillier 2009; Oliveira 2016; Ratti 2004
		Choice (Space Syntax)	Hillier 2009; Oliveira 2016; Ratti 2004
		Depth Distance (Space Syntax)	Hillier 2009; Oliveira 2016; Ratti 2004
		Accessibility to economic centres	Dadashpoor and Rostami 2017; Dony et al. 2015; Goswami and Lall 2016; Kanuganti et al. 2016

ISOCARP Knowledge for Better Cities

CONCEPTS	VARIABLES	INDICATORS	INDICATOR SOURCE
	1.2 Built Environment	Accessibility to educational facilities	Dadashpoor and Rostami 2017; Dony et al. 2015; Goswami and Lall 2016; Kanuganti et al. 2016
		Accessibility to health institutions	Dadashpoor and Rostami 2017; Dony et al. 2015; Goswami and Lall 2016; Kanuganti et al. 2016
		Accessibility to public transport nodes	Dadashpoor and Rostami 2017; Dony et al. 2015; Goswami and Lall 2016; Kanuganti et al. 2016
		KM of primary roads per sqkm	UN-Habitat 2016
		KM of secondary roads per sqkm	adapted from UN-Habitat 2016
		KM of paved roads per sqkm	adapted from UN-Habitat 2016
		KM of unpaved roads per sqkm	adapted from UN-Habitat 2016
		Number of nodes per sqkm	UN-Habitat 2016
		Building density	Adolphe 2001; Hillier 2009; Jacobs 1961; Pont and Haupt 2009; UN-Habitat 2016
		Site occupancy index	Adolphe 2001; Hillier 2009; Jacobs 1961; Pont and Haupt 2009
		Average plot size	Hillier 2009; Jacobs 1961; Pont and Haupt 2009
		Average building size	Hillier 2009; Jacobs 1961; Pont and Haupt 2009
		Building proximity	Adoplhe 2000, Dadashpoor and Rostami 2017, Dave 2010
	1.3 Land Use	Amount public space	Adoplhe 2000, Dadashpoor and Rostami 2017, Jacobs 1961, Pont and Haupt 2009
		Amount green space	Adoplhe 2000, Dadashpoor and Rostami 2017, Jacobs 1961, Pont and Haupt 2009
		Percentage of mixed functions	Adoplhe 2000, Dadashpoor and Rostami 2017, Jacobs 1961, Pont and Haupt 2009
		Settlement type	EARF research project
2 RISK EXPOSURE	2.1 Probability	Elevation	UN-Habitat 2011
		Slope	UN-Habitat 2011
		Distance to flood prone area	UN-Habitat 2011
		Disaster occurrence in last 2 years	EARF research project
	2.2 Secondary Risks	Number of malaria cases	adapted from UN Pulse Lab
		Number of typhoid cases	adapted from UN Pulse Lab
		Number of dysentery cases	adapted from UN Pulse Lab
3 ADAPTIVE CAPACITY	3.1 Resources	Household income	Adger 2006; Adger 2007; ARCC 2013; Weis et al. 2016
	3.2 Behaviour	Social integration	Adger 2006; Adger 2007; ARCC 2013; Weis et al. 2016
		Perception of risk	EARF research project
		Level of 'formality'	Adger 2006; Adger 2007; Cordona et al. 2012; Haas 2017
	3.3 Knowledge and Information	No. of active institutions	Adger 2006; Adger 2007; Williams et al. 2015
		Internet use	Adger 2006; Adger 2007; Williams et al. 2015
		Level of education	Adger 2006; Adger 2007; ARCC 2013; Weis et al. 2016
4 SENSITIVITY	4.1 Human sensitivity	Population density	Hillier 2009; Jacobs 1961; Pont and Haupt 2009
		Gender	Adger 2006; Adger 2007; Cordona et al. 2012
		Age	Adger 2006; Adger 2007; Cordona et al. 2012
	4.2 Building sensitivity	Built floor quality	Adger 2007; Dickson et al. 2012; Dodman et al. 2015; Elrich-Barr et al. 2014; Jones 2010; Schreiner 2012
		Built wall quality	Adger 2007; Dickson et al. 2012; Dodman et al. 2015; Elrich-Barr et al. 2014; Jones 2010; Schreiner 2012
		No. of rooms	Adger 2007; Dickson et al. 2012; Dodman et al. 2015; Elrich-Barr et al. 2014; Jones 2010; Schreiner 2012
	4.3 Infrastructure sensitivity	Road sensitivity	EEA 2016; Engle 2011; Isunju 2016; Weis 2016
		Water provision sensitivity	EEA 2016; Engle 2011; Isunju 2016; Weis 2016
		Educational facility sensitivity	EEA 2016; Engle 2011; Isunju 2016; Weis 2016
		Health institution sensitivity	EEA 2016; Engle 2011; Isunju 2016; Weis 2016
		Religious institution sensitivity	EEA 2016; Engle 2011; Isunju 2016; Weis 2016

4. Application

Before the methodology can be used, several steps need to be undertaken. They include defining the sample selection and size. Furthermore, the application can be divided into data assessment, which includes underlying steps and calculations, and the analysis, which interprets the resulting variables.

4.1 Sample size and selection

The spatial analysis is conducted at two levels, firstly the GKMA and secondly the SA. The latter is selected through a two-step sample process. As a first step, the EARF research team established a purposive sample of some parishes to cover a wide variety of land development patterns. Two corridors were distinguished: one from the centre to the north-west (along Hoima Road), and one to the east (along Jinja Road). For the household survey which was carried out as part of the research compendium, about 2800 households were enumerated which are equally distributed over eight strata (four different residential housing types and core and peripheral locations). Inside these, the households were selected through a random generation of coordinates. The enumerators started off from these coordinates and then approached the closest household.

In the second step, areas were selected inside these corridors through another purposive sample for the in-depth analysis of this thesis. This selection was done based upon a broad coverage of the different housing types, levels of centrality and vulnerability and distances to flood-prone areas, as well as the availability of in-depth spatial data. The data collection method is a mixed-method approach using existing quantitative secondary data and semi-structured expert interviews, observations to distinguish the public transport nodes, as well as the conducted EARF household survey. These strategies were chosen to garner a broad data set of both quantitative and qualitative data to understand the distribution and prevalence of risk and its interrelation with urban form. Furthermore, the interviews are used to weigh the various indicators according to their importance to achieve a representative weighting as part of the aggregation process. This process is done through a participatory multi-criteria decision analysis which lets the participants compare and assign values for each indicator in comparison to the other indicators in the same sub-group[iii] (Scott 2005, pp. 705-706). Lastly, papers and reports which focus on the climate change related risk improve the data input for the analysis of the data. The gathered qualitative data mainly assist the interpretation of the quantitative findings while also supporting the process of quantitative data collection as well as the focus, selection and weighting of the secondary data indicators.

The collected secondary quantitative data comes from various sources. Firstly numerous information from governmental institutions: i.e. the jurisdictional boundaries, the national household survey of 2014 as well as the flood-prone areas. Secondly, information produced as part of the EARF project is integrated: mainly the different housing typologies and the household survey. Additionally, other data sets are imputed from a range of recent datasets and reports which examine one particular issue in detail: amongst others, the reports on the vulnerability of Kampala (UN-Habitat 2011) and the World Bank report on economic centres (Goswami and Lall 2016). Lastly, for quantifying urban form and accessibility to various facilities, in-depth spatial data is required which is mainly collected from OpenStreetMap and extended through own mapping.

4.2 Data assessment

The conducted data assessment of the spatial elements consists of mainly four different parts:

1. Assigning existing geo-referenced data to cells.
2. Incorporating various types of spatial analysis and including basic calculations like counting the number of buildings or the length of streets per cell.
3. The Urban Network Analyst Toolbox for ArcGIS of the City Form Lab is used to calculate integration, choice and depth distance, based on infrastructure data from OpenStreetMap.
4. The Variable-width Floating Catchment Area (VFCA) method which builds upon the Two-step Floating Catchment Area Method (2SFCA) is used to calculate accessibility to economic centres, different facilities or functions.

The latter method was originally developed to calculate the accessibility of the population to health facilities. However, Dony et al. (2015) adapted the methodology to include other types of functions and takes varying weights or levels of attractiveness into consideration (in their case for example the size and number of amenities of parks). It is therefore seen as the most appropriate method to calculate accessibility to various functions which differ between their characteristics. As an example, this research calculates the accessibility to public transport nodes. However, one node just serves a few city-wide transport modes while others also cater for national or international routes. Therefore, an adapted weighting is required to take these differences into consideration. Lastly, the VFCA like the 2SFCA depends on the selection of the calculation method of distances. For this, different approaches exist, amongst other the Euclidean distance, the time-distance or network distance (Kanuganti et al. 2016). The Euclidean distance is chosen[iv] and measured through the Network Analyst Toolbox of ArcGIS.

4.3 Data analysis

The resulting geo-referenced quantitative data of the selected areas allow for regression analyses to distinguish patterns and understand which factors are interrelated. Through the qualitative data of the interviews and previous reports and articles, the quantitative results can be further explained, interpreted and situated into the larger context of risk distribution and the resulting spatial (in-)justice. To be able to compare all data with varying units, the values are normalised before further analysis after which each value is represented by a number between 0 and 1. Furthermore, to reduce the number of indicators to a manageable size and eradicate non-essential ones, two steps are undertaken. First, a redundancy analysis is conducted to identify indicators which nearly completely correlate and, therefore, mainly provide the same information. Secondly, the various indicators are aggregated to compound scores for each variable to simplify the comparison and regression analysis.

Afterwards, mainly two analysis approaches are applied. In the first step, the Ordinary Least Squares (OLS; Hutcheson 2011) method is applied, which distinguishes the unknown factors in a linear regression. This means, that for example the compound score of urban form of each cell is compared to the variables of risk exposure, adaptive capacity and sensitivity and the impact value of each aggregated indicator are calculated based on the minimal average coefficient of determination (R^2). Based on the findings of the OLS analysis, the most significant factors can be distinguished and further studied individually through selected multiple regression analyses. This regression analysis is conducted in several steps and afterwards scaled down. This anticipated regression analysis is conducted in several steps and afterwards scaled down. The general formula of the OLS-regression is as follows:

$$\mathbf{y^1 = ß^1x_i^1 + ß^2x_i^2 + \ldots + ß^px_i^p + \varepsilon_i}$$

In the first two separate analyses, the aggregated scores of the two concepts (Urban Form and Flood-related urban risks) represent the $\mathbf{y^1}$ on the left and the aggregated variable scores constitute the $\mathbf{x_i^p}$ values on the right with the objective to distinguish the broader $\mathbf{ß^p}$ values. Afterwards, a more detailed analysis is conducted which looks at the different variable interrelations independently by again keeping the two concept scores as $\mathbf{y^1}$ but splitting the variables into the constituting indicators. The latter has the objective to distinguish the strongest correlations and simultaneously exclude possible non-correlated indicators from further analysis. Lastly, the strongest correlations are studied by multiple regression analysis to investigate them in greater depth.

As a second step, a classification of the cells is undertaken in order to distinguish patterns and expand the findings to the whole city based on shared characteristics. This is done through a Principal Component Analysis, which combines correlating elements and combines them with linearly unrelated aspects and therefore creates a categorisation based on similarity and difference of all input values. The method can be best understood by imagining a coordinate system in which the principal component axis represents the first correlating elements and every further mostly unrelated component results in a perpendicular axis to the first one. The same process is repeated for each element until all axes are situated in relation to each other and the individual studied subjects are located in a multi-dimension coordinate system. This distribution then leads to a categorisation which best represents the similarities and differences of the various input variables.

The expected outcomes are an indication of the interrelations of various sub-variables as well as the interdependency of particular factors to all other relevant ones. Furthermore, the Principal Component Analysis shall lead to a classification of the studied cells and therefore visualises patterns and can allow generalisations up to a certain degree for the whole urban area of Kampala. Therefore, the outcomes of the study are partly descriptive and partly prescriptive. Some outcomes solely represent already existing information in combined and more detailed manners, while others, like specific interrelations between factors, give an indication about expectable developments in the future and how one might affect another one and therefore also where and what kind of interventions might be most fruitful to anticipate further marginalisation and spatial inequalities.

5. Conclusion

This methodological approach to measure risk exposure, adaptive capacity and sensitivity and contrast it with urban form, allows for a quantification of spatial climate change injustice in the context of limited data availability and needs considerably less information and technological resources than existing approaches. However, it results in spatial pattern distinction and assists to better understand the social and environmental urban development. Furthermore, whenever new data becomes available or information is updated (spatial information), the model can be extended and adapted to make temporal studies and analyse how the urban areas develop over time.

However, the current limitations of the methodology are on the one hand the flood-risk model and secondly the assessment of social networks as part of the adaptive capacity. However, the findings should be able to paint a better picture of Kampala's current situation while also helping to understand the spatial injustice of climate change consequences in similar urban contexts of SSA. Based on the results of the analysis, which is currently conducted, better and more precise policy decisions and spatial interventions can be developed by the responsible organisations and their success assessed over time.

---

[i] This paper builds upon and contains sections of the author's master thesis research at the Institute for Housing and Urban Development Studies (IHS), Erasmus University Rotterdam, and is integrated in the broader research project 'Spatial Inequality in Times of Urban Transition', conducted by the IHS, the Development Planning Unit (University College London) and IPE Tripleline and is funded by the British Government's East Africa Research Fund.

[ii] Indicator attributes are not included due to the scope of paper but available upon request.

[iii] The most important indicator gets a score of 100 points, and other indicators are compared to the first and given scores according to the relative importance.

[iv] Euclidean distance, defined as the distance in meters by using the existing network in the shortest possible way, does not consider varying infrastructure densities and time-distance. Therefore, it is challenging to select the right network-distance due to strongly varying modes of transport. Even if different qualities and sizes of roads (e.g., paved/unpaved) are not accounted for, it appears to be most accurate under the given circumstances.

References

Adger, W. N. (2006) "Vulnerability", Global Environmental Change, Vol. 16

Adolphe, L. (2001) "A simplified model of urban morphology: application to an analysis of the environmental performance of cities", Environment and Planning B: Planning and Design, Vol. 28

Althor, G., Watson, J. E. M. and Fuller, R. A. (2016) "Global mismatch between greenhouse gas emissions and the burden of climate change", Scientific Reports, Vol. 6

Anaba, L. A. et al. (2017) "Application of SWAT to Assess the Effects of Land Use Change in the Murchison Bay Catchment in Uganda", Computational Water, Energy, and Environmental Engineering, Vol. 6

Bartlett, S. (2008) "Climate change and urban children: impacts and implications for adaptation in low- and middle-income countries", Environment & Urbanization, Vol. 20 No. 2

Brecht, H., Deichmann, U. and Wan, H. G. (2013) A Global Urban Risk Index. World Bank: Policy Research Working Paper 6506

Brooks, N. (2003) Vulnerability, risk and adaptation: A conceptual framework. Tyndall Centre for Climate Change Research: Working Paper 38

Cannon, M. (2014) Uganda Vulnerability Index Assessment Results. USAID

Cardona, O.-D. et al. (2012) Determinants of Risk: Exposure and Vulnerability. In: Field, C. B., 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge: Cambridge University Press

Dadashpoor, H. and Rostami, F. (2017) "Measuring spatial proportionality between service availability, accessibility and mobility: Empirical evidence using spatial equity approach in Iran", Journal of Transport Geography, Vol. 65

Dave, S. (2010) "High Urban Densities Developing Countries: A Sustainable Solution?", Built Environment, Vol. 36 No. 1

Dickson, E., Baker, J. L., Hoornweg, D. and Tiwari, A. (2012) Urban Risk Assessments: Understanding Disaster and Climate Risk in Cities. International Bank for Reconstruction and Development, The World Bank

Dimanin, P. (2012) Exploring livelihoods of the urban poor in Kampala, Uganda: An institutional, community, and household contextual analysis. Action Contre la Faim

Dodman, D., Soltesova, K., Satterthwaite, D. and Tacoli, C. (2015) Understanding the Assessment and Reduction of Vulnerability to Climate Change in African Cities: A Focus on Low-Income and Informal Settlements. International Institute for Environment and Development

Dony, C. C., Delmelle, E. M. and Delmelle, E. C. (2015) "Re-conceptualizing accessibility to parks in multi-model cities: A Variable-width Floating Catchment Area (VFCA) method", Landscape and Urban Planning, Vol. 143

Engle, N. L. (2011) "Adaptive capacity and its assessment", Global Environmental Change, Vol. 21

EEA (2016) European Climate Adaptation Platform. Adaptation Support Tool. European Environment Agency

Fainstein, S. S. (2010) The Just City. Ithaca: Cornell University Press

Fragkias, M., Lobo, J., Strumsky, D. and Seto, K. C. (2013) "Does Size Matter? Scaling of CO2 Emissions and U.S. Urban Areas", PloS One, Vol. 8 No. 6

Fura, G. D. (2013) Analysing and Modelling Urban Land Cover Change for Run-Off Modelling in Kampala, Uganda. University of Twente, Faculty of Geo-Information Science and Earth Observation: Master thesis

Gehl, J. (2010) Cities for People. Washington: Island Press

GIZ (2014) The Vulnerability Sourcebook. Concept and guidelines for standardised vulnerability assessments. Bonn: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Godfrey, S., Niwagaba, C., Howard, G. and Tibatemwa, S. (2003) Water Safety Plans for Utilities in Developing Countries – A case study from Kampala, Uganda

Goswami, A. G. and Lall, S. V. (2016) Jobs in the City: Explaining Urban Spatial Structure in Kampala. World Bank Group, Social, Urban Rural and Resilience Global Practice Group: Policy Research Working Paper 7655

Hillier, B. (2009) "Spatial Sustainability in Cities: Organic Patterns and Sustainable Forms", Proceedings of the 7th International Space Syntax Symposium. Stockholm: KTH

Hutcheson, G. D. (2011) Ordinary Least-Squares Regression. In Moutinho, L. and Hutcheson, G. D. (2011) The SAGE Dictionary of Quantitative Management Research. London: SAGE Publishing

IPCC (2001) Climate Change 2001: Impacts, Adaptation, and Vulnerability. Intergovernmental Panel on Climate Change

IPCC (2007) Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press

Isunju, J.B., Orach, C. G. and Kemp, J. (2015) "Hazards and vulnerabilities among informal wetland communities in Kampala, Uganda", Environment & Urbanization, Vol. 28 No. 1

Isunju, J. B. (2016) Spatiotemporal Analysis of Encroachment on Wetlands: Hazards, Vulnerability and Adaptations in Kampala City, Uganda. PhD Dissertation, Stellenbosch University

Jabareen, Y. R. (2006) "Sustainable Urban Forms: Their Typologies, Models, and Concepts", Journal of Planning Education and Research, Vol. 26

Jacobs, J. (1961) The Death and Life of Great American Cities. New York: Vintage Books.

Jones, L., Ludi, E. and Levine, S. (2010) Towards a characterisation of adaptive capacity: a framework for analysing adaptive capacity at the local level. Overseas Development Institute

Kanuganti, S., Sarkar, A. K. and Singh A. P. (2016) "Quantifying Accessibility to Health Care Using Two-step Floating Catchment Area Method", Transport Research Procedia, Vol. 17

Karolien, V. et al. (2012) "Urban growth of Kampala, Uganda: Pattern analysis and scenario development", Landscape and Urban Planning, Vol. 106 No. 2

KCCA (2016) Kampala Climate Change Action

Louf, R. and Barthelemy, M. (2014) "Scaling: Lost in Smog", Environment and Planning B: Planning and Design, Vol. 41

Mabasi, T. (2009) Assessing the Impacts, Vulnerability, Mitigation and Adaptation to Climate Change in Kampala City. Kampala: Fifth Urban Research Symposium 2009

MoGLSD (2017) Uganda Management of Social Risk and Gender Based Violence Prevention and Response Project: Environmental Management Framework

Mukama, T. et al. (2016) "Practices, Concerns, and Willingness to Participate in Solid Waste Management in Two Urban Slums in Central Uganda", Journal of Environmental and Public Health

Myers, G. (2016) Urban Environments in Africa: A critical analysis of environmental politics. Bristol: Policy Press

Nyakaana, J. B., Sengendo, J. and Lwasa, S. (2008) Population, Urban Development and the Environment in Kampala City and its Environs. Makerere University Kampala

Oliveira, E. A., Andrade, J. S. and Makse, H. A. (2014) "Large cities are less green", Scientific Reports, Vol. 4

Oliveira, V. (2016) Urban Morphology: An Introduction to the Study of the Physical Form of Cities. The Urban Book Series. Basel: Springer International Publishing

Osuteye, E., Johnson, C. and Brown, D. (2017) "The data gap: An analysis of data availability on disaster losses in sub-Saharan African cities", International Journal of Disaster Risk Reduction, Vol. 26

Parnell, S. and Walawage, R. (2010) Sub-Saharan African urbanisation and global environmental change. In: Parnell, S. and Pieterse, E. eds. (2014) Africa's Urban Revolution. London: Zed Books

Pelling, M. and Wisner, B. eds. (2009) Disaster Risk Reduction: Cases from Urban Africa. Abingdon: Taylor & Francis

Pelling, M., Brown, D., Lwasa, S. and Chen, F. (2016) Cities and Disaster Risk Reduction. Policy Recommendations

Pieterse, E. and Parnell, S. (2010) Africa's urban revolution in context. In: Parnell, S. and Pieterse, E. eds. (2014) Africa's Urban Revolution. London: Zed Books

Pont, M. B. and Haupt, P. (2009) Space, Density and Urban Form. Technical University Delft: Doctoral Thesis

Ratti, C. (2004) "Space syntax: some inconsistencies", Environment and Planning B: Planning and Design, Vol. 31

Richmond, A., Myers, I. and Namuli, H. (2018) "Urban Informality and Vulnerability: A Case Study in Kampala, Uganda", Urban Science, Vol. 2 No. 22

Schreiner, M. (2012a) Uganda 2012 Poverty Probability Index (PPI): Design Memo. Poverty Probability Index

Schreiner, M. (2012b) PPI for Uganda 2012. Poverty Probability Index

Scott, L. (2005) "Participatory multi-criteria decision analysis: a new tool for integrated development planning", Development Southern Africa, Vol. 22 No. 5

United Nations (2015) "Transforming our world: The 2030 Agenda for Sustainable Development", 69th General Assembly

UN (2016) Habitat III, New Urban Agenda

UN-Habitat (2007) Situation Analysis of Informal Settlements in Kampala

UN-Habitat (2009) Climate Change Assessment for Kampala, Uganda: A Summary

UN-Habitat (2011) Vulnerability Assessment of Climate Change in Kampala and Uganda

UN-Habitat (2014) The State of African Cities 2014: Re-imagining sustainable urban transitions

UN-Habitat (2016) Measurement of City Prosperity: Methodology and Metadata

WCED (1987) Report of the World Commission on Environment and Development: Our Common Future.

Weis, S. W. M. et al. (2016) "Assessing vulnerability: an integrated approach for mapping adaptive capacity, sensitivity, and exposure", Climate Change

Williams, K. (2014) Urban form and infrastructure: a morphological review. UK Government, Office for Science

Williams, C., Fenton, A. and Huy, S. (2015) "Knowledge and adaptive capacity", Nature Climate Change, Vol. 5