Landslide Risk Assessment for the Built Environment in Sub-Saharan Africa

Peter Redshaw, Tom Dijkstra, Matthew Free, Colm Jordan, Anna Morley, and Stuart Fraser

Abstract

This paper presents an overview of the findings from a series of country-scale landslide risk assessments conducted on behalf of the governments of five Sub-Saharan countries, the World Bank and the Global Facility for Disaster Reduction and Recovery (GFDRR). Ethiopia, Kenya, Uganda, Niger and Senegal sample a wide range of Sub-Saharan Africa's different geographies and are characterised by contrasting levels of development. Landslide hazard, exposure and vulnerability therefore differ from country to country, resulting in significant spatial variation of landslide risk. In East Africa; Ethiopia, Kenya and Uganda are characterised by mountainous and seismically active terrain which results in a relatively high landslide hazard. In conjunction with rapid urbanisation and a population which is expected to rise from around 170 million in 2010 to nearly 300 million in 2050, this means that landslides pose a significant risk to the built environment. In West Africa, a combination of low landslide hazard and lower exposure in Niger and Senegal results in comparatively low landslide risk. This paper also describes areas with perceived misconceptions with regard to the levels of landslide risk. These are areas of only low to moderate landslide hazard but where urbanisation has resulted in a concentration of exposed buildings and infrastructure that are vulnerable to landslides, resulting in higher landslide risk.

Keywords

Regional landslide risk • Built environment • Ethiopia • Kenya • Uganda • Niger • Senegal

P. Redshaw (✉) · M. Free · A. Morley
Ove Arup & Partners International Ltd, 13 Fitzroy Street, London, W1T 4BQ, UK
e-mail: peter.redshaw@arup.com

M. Free
e-mail: matthew.free@arup.com

A. Morley
e-mail: anna.morley@arup.com

T. Dijkstra · C. Jordan
British Geological Survey, Environmental Science Centre, Keyworth, Nottingham, NG12 5GG, UK
e-mail: tomdij@bgs.ac.uk

C. Jordan
e-mail: cjj@bgs.ac.uk

S. Fraser
Global Facility for Disaster Reduction and Recovery—Innovation Lab, Washington, D.C., USA
e-mail: sfraser@worldbank.org

M. Mikoš et al. (eds.), *Advancing Culture of Living with Landslides*,
DOI 10.1007/978-3-319-53483-1_2

Introduction

Sub-Saharan Africa is characterised by landscapes ranging from high mountains to low relief floodplains; by rainfall which can be desperately sparse or exceptionally intense; and by cities, towns and villages which can be both overcrowded and poorly planned or remote and isolated. The impact of landslides on these diverse environments is therefore highly variable.

In Uganda's Bududa district, near the border with Kenya, landslides have caused hundreds of fatalities and left many thousands permanently displaced due to landslide damage caused to the built environment (Kitutu 2010). In 2010 one event killed over 350 people and initiated government calls for the mass relocation of settlements away from the mountainous slopes of Mount Elgon (Terra Daily 2010). However, little subsequent action means that vulnerable communities remain at great risk. In Ethiopia, the northern highlands and many urban areas face a similar threat from landslides. The rapid expansion of Dessie Town, has resulted in unregulated or poorly planned development in areas of high landslide risk. The construction of houses, roads, bridges and utilities has in many cases been interpreted to have contributed to occurrences of landslides in population centers, indicating that landslide processes are often poorly understood (Fubelli et al. 2013).

To better understand landslide risk and to inform the provision of more detailed risk management initiatives, the World Bank and the GFDRR is supporting the development of new landslide risk information for Sub-Saharan Africa, starting with five countries: Ethiopia, Kenya, Uganda, Niger and Senegal. This study forms part of a wider initiative by the GFDRR to characterise multi-hazard risk in Sub-Saharan Africa.

Regional Landslide Risk Analysis

Regional landslide risk analysis aims to provide a better understanding of the spatial distribution of the risk posed to populations, structures, infrastructure and other assets, from damage, destruction or death as a result of a landslide. Corominas et al. (2014) summarize this process in five steps: (1) Hazard identification, (2) Hazard assessment, (3) Exposure identification, (4) Vulnerability assessment, and (5) Risk estimation.

Hazard Identification

Landsliding in Ethiopia, Kenya and Uganda is widespread and is interpreted to be influenced by topography (Ayalew and Yamagishi 2004; Kitutu 2010), geology (Kitutu 2010), anthropogenic causes (Ayelew et al. 2009; Broothaerts et al. 2012), hydrological processes (Abebe et al. 2010; Ayalew 1999; Beyene et al. 2012) and long term geomorphological evolution (Ayalew and Yamagishi 2004; Vařilová et al. 2015).

In Ethiopia, Ayalew et al. (2009) report landslides occurring preferentially in basaltic terrain and along the boundary between basalt and limestone in the Blue Nile Basin Region. Examples of major landsliding in Ethiopia include the Gembechi Village Landslide (Bechet Valley, 1960), the Wudmen Landslide (1993) and the Uba Dema Village Landslide (1994) (Ayalew 1999).

Maina-Gichaba et al. (2013) provide an overview of landslide occurrences in Kenya, identifying a number of important drivers in the generation of landslides, including anthropogenic factors related to land tenure, including unsustainable land use practices and particularly land fragmentation. Deforestation in the mountainous districts of Kenya has also been linked to increased landscape sensitivity. Ngecu and Ichang'I (1999) report on the impact of landslides in the Aberdare Mountains in Kenya, where between 1960 and 1980 around 40 major landslides occurred, mobilising approximately 1000,000 m^3 of material in an area of approximately 300 km^2. Further reports of major landslides in Kenya include the 1986 Mukurweini Landslide, the 1991 Gacharage Landslide, and the 1997 Maringa Landslide.

Kitutu et al. (2011; building on earlier work by Knapen et al. 2006) assessed farmers understanding and perception of landslides in Bududa district, Eastern Uganda. Farmers were able to provide their experiences, understanding and observations, which highlighted that steep slopes, areas with concavities and those with flowing groundwater were identified as being prone to landslides. Farmers also identified that coarse, permeable soils are prone to landsliding, responding rapidly to intense precipitation. In these areas, terraces are not popular amongst farmers because these are known to promote water infiltration and trigger landslides.

The Rwenzori Mountains form one of the regions in Uganda where landslides have made a significant impact (NEMA 2007), with 48 landslides and flash-flood events reported by Jacobs et al. (2015).

Reporting and analysis of landslides in Senegal is concentrated around the Dakar coastline. Fall et al. (2006a, b) describe six landslide locations set within a short section of cliffs which were analysed, enabling the determination of landslide zones and the geomorphological development to be interpreted. Wang et al. (2009) report a study of natural hazards in the sub-urban areas of Dakar, covering approximately 580 km^2, although the focus of the study is on coastal erosion and flooding.

To date, no studies have been identified which discuss landslide hazard or risk in Niger.

For all five countries of this study, no suitable landslide inventories were available for inclusion in the landslide hazard assessment stage. Satellite imagery was used to verify and inform interpretation of the landslide hazard.

Hazard Assessment

The hazard identification stage contributes to an interpretation of landslide susceptibility, which, when combined with approximations of landslide triggers, enables the estimation of landslide hazard.

Landslide susceptibility assessment is based on the premise that a range of parameters can be combined to obtain an approximation of the conditions in the landscape that determine the propensity of slopes to generate landslides. To obtain a score for landslide susceptibility, the components of each factor that contribute to landslide susceptibility are analysed, re-classified and then mapped across the study area. The relative contribution of an individual susceptibility factor (S_n) is regulated through multiplication with a weight (W_n). The ranked and weighted factors are then combined to derive an expression of landslide susceptibility (L_s):

$$L_s = (S_1 \times W_1) + (S_2 \times W_2) + (S_n \times W_n)$$

Due to the vast land-area and regional nature of this study, the selection of individual susceptibility factors needed to consider both the applicability across a range of different terrains and climates, and the availability of data for each country of interest. There was therefore a focus on primary geological and morphometric factors such as slope angle, bedrock lithology, and soil type. The key susceptibility factors were identified through review of relevant smaller-scale studies in Sub-Saharan Africa (e.g. Temesgen et al. 2001; Van Den Eeckhaut et al. 2009; Musinguzi and Asiimwe 2014; Meten et al. 2015).

The effect of landslide triggers was accounted for by applying a multiplier to the susceptibility score to give an expression of landslide hazard. Two landslide triggers were considered; rainfall and earthquakes. Ethiopia, Kenya, Uganda, Niger and Senegal are all subject to rainfall-triggered landslides. Ethiopia, Kenya and Uganda only are subject to earthquake-triggered landslides due to their proximity to the seismically-active East African Rift Valley. The rainfall triggering factor was based upon a weighted combination of long-term average rainfall and 100 year extreme monthly rainfall (determined from the Global Precipitation Climatology Centre monthly time series data due to the lack of available region-specific data). The earthquake triggering factor was based upon a weighting factor applied to the estimated peak ground acceleration with a 500 year return period (PGA_{500}). The use of threshold landslide triggering values (of either PGA or rainfall intensity-duration) was not possible at this scale of analysis due to the lack of available landslide inventories and high resolution region-specific data.

The population of landslide hazard scores is partitioned as a proportion of the maximum obtainable score to designate hazard classes A–E (following the rationale of Mastrandrea et al. 2010, where A: 0–10%, B: 10–33%, C: 33–66%, D: 66–90% and E: 90–100%).

Due to the lack of available complete landslide inventories it was not possible to use the probability of certain trigger events to estimate the frequency of occurrence of landslides of different sizes. In the absence of landslide inventories, an approximation of the probability of landslide occurrence was obtained using an approach similar to that used by Nadim et al. (2006, 2013). This approach uses the score of landslide hazard as an indicator/proxy for approximate annual frequency of a landslide event. This is based on expert interpretation of the likelihood of occurrence in cases where sufficient event data exists (Nadim et al. 2006, 2013).

To determine the annual frequencies of different sized landslides, published relationships between landslide size and landslide frequency are used. Van Den Eeckhaut et al. (2007) compiled and reviewed 27 landslide area/volume—frequency studies describing landslide frequency from regions around the world and found that the annual frequency of landslides versus landslide size within a region could be modelled using a negative power-law with slope β. The average value of this expression was found to give β = 2.3. It should be noted that in many areas, the annual frequency of landslides will deviate from this relationship based on local factors which cannot be captured by this analysis. However, at sub-continental scale, this methodology provides a systematic approach for estimating landslide size-frequency relationships and hence facilitating regional estimates of landslide risk.

A landslide is defined as a combination of the landslide source area and the landslide debris area. The mechanism or rate by which material moves from the source area to the debris area is not considered.

Landslide runout analysis is not typically completed for landslide hazard studies at regional or country scale because the resolution of the input data for such studies is usually too coarse to interpret flow paths (Horton et al. 2008; Corominas et al. 2014). This study estimates the probability that a given exposed asset will be affected by a landslide of a given size based on the ratio of the sum of the landslide area and the asset footprint area to the grid square area.

Figure 1 presents an example of the landslide hazard maps produced at a spatial resolution of approximately 0.25 km^2.

Exposure Identification

The inventory of elements at risk (or 'exposure') for this study was provided by a consortium comprising ImageCat Inc., CIESIN, University of Colorado and SecondMuse under a related project administered by the GFDRR. Exposure information was provided for the built environment, population and GDP. The built environment dataset comprised information on the location and structural attributes of buildings, the location of road networks and the location of rail networks. Also provided was the approximate rebuild cost associated with structures and infrastructures of different typologies.

Vulnerability Assessment

The physical vulnerability of structures and infrastructure describes the probable response to being affected by a landslide of a given size. The ability of a structure to resist damage therefore controls not just the economic losses which result from having to rebuild or repair it, but the vulnerability of the persons within it. For site specific landslide risk assessment the concept of physical vulnerability can be greatly expanded upon to consider the influence of landslide mechanism, debris type, building typology and the position of the exposed building relative to the landslide (e.g. Mavrouli et al. 2014). Region and country-scale studies such as described in this paper are better suited to

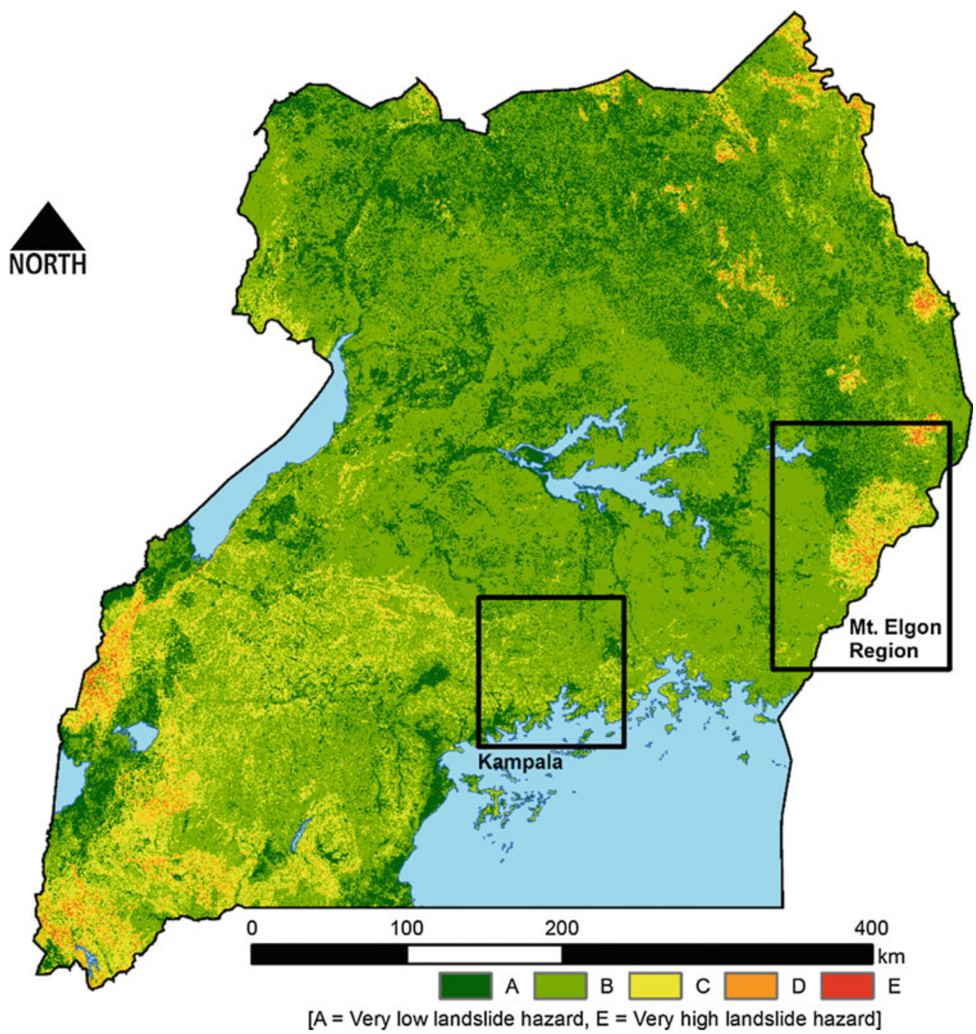

Fig. 1 Rainfall-triggered landslide hazard assessment for Uganda

methodologies which incorporate broad categories of structure typology (e.g. Du et al. 2013).

This study uses fragility functions, which estimate the probability that a certain damage state will occur as a result of a structure being affected by a landslide of a certain size. In addition, loss ratios are applied. These define what proportion of the rebuild value of a given structure is lost as a result of incurring a particular level of damage.

Risk Estimation—Results Overview

Risk is expressed as the product of the probability of hazard occurrence (e.g. a damaging landslide event) and its adverse consequences (Lee and Jones 2004).

In each of Ethiopia, Kenya and Uganda, landslides are estimated to cause approximately \$6 M–\$8 M (M = Million) worth of damage to the general building stock each year. For Niger and Senegal, average annualized losses (AAL) are estimated to be significantly less, with estimates in the region of \$1 M (Table 1).

AAL resulting from landslide damage to roads and railways is significantly less than AAL resulting from landslide damage to the general building stock. In Ethiopia, Kenya and Uganda, estimates are less than \$0.5 M, with significantly lower figures estimated for Niger and Senegal (Table 2).

Results are calculated based on a 0.25 km^2 grid and aggregated to Administrative Level 1 boundaries to allow clearer communication to key stakeholders and other intended end-users of the risk metrics. Figure 2 shows an example of the 0.25 km^2 resolution risk outputs for Uganda. Figure 3 presents the aggregated Administrative Level 1 landslide risk estimates for Ethiopia, Kenya, Uganda, Niger and Senegal (in terms of AAL in million USD). Note that the AAL estimates shown on Fig. 3 are in terms of absolute estimated annual losses to the built environment and are not shown normalized over the exposed value per administrative region. For this reason, Uganda, with its 112 Administrative Regions, shows lower AAL per region than, for example Kenya (which only has 8 official Administration Level 1 sub-divisions) despite similar nationwide estimated annual losses (Tables 1 and 2).

Discussion

The difference in landslide risk estimates between the East African countries and those in the central and western parts of Sub-Saharan Africa is interpreted to be the combined result of both increased landslide hazard in East Africa, and lower total-value of exposed assets in the West African countries of Niger and Senegal.

The relatively low AAL for transport infrastructure is possibly the result of a combination of two factors. Firstly, railway networks in Sub-Saharan Africa are generally not widely developed (and thus the total exposure is very low) and railways are constructed using low gradients, avoiding areas of steep topography (and hence typically avoiding areas of the highest landslide hazard).

Secondly, the majority of road networks in Sub-Saharan Africa are unpaved, with a typical relatively low replacement cost of \$9600/km (as estimated by ImageCat Inc., CIESIN, University of Colorado and SecondMuse). Roads are therefore comparatively cheap to repair in contrast to buildings.

Landslide risk is estimated on the basis of information on landslide hazard, exposure and vulnerability. This study indicates that exposure and vulnerability are particularly

Table 1 Estimated AAL to the general building stock from landslide-induced damage

Country	Exposure (\$M)	AAL (\$M)	AAL (% of exposure)
Ethiopia	311,834	6.115	0.00196
Kenya	537,546	8.280	0.00154
Uganda	563,621	8.915	0.00158
Niger	180,589	0.934	0.00052
Senegal	237,243	0.863	0.00036

Table 2 Estimated AAL to the roads and railways from landslide-induced damage

Country	Exposure (\$M)	AAL (\$M)	AAL (% of exposure)
Ethiopia	8044	0.302	0.00375
Kenya	7510	0.149	0.00197
Uganda	6687	0.110	0.00162
Niger	3026	0.019	0.00059
Senegal	4138	0.029	0.00065

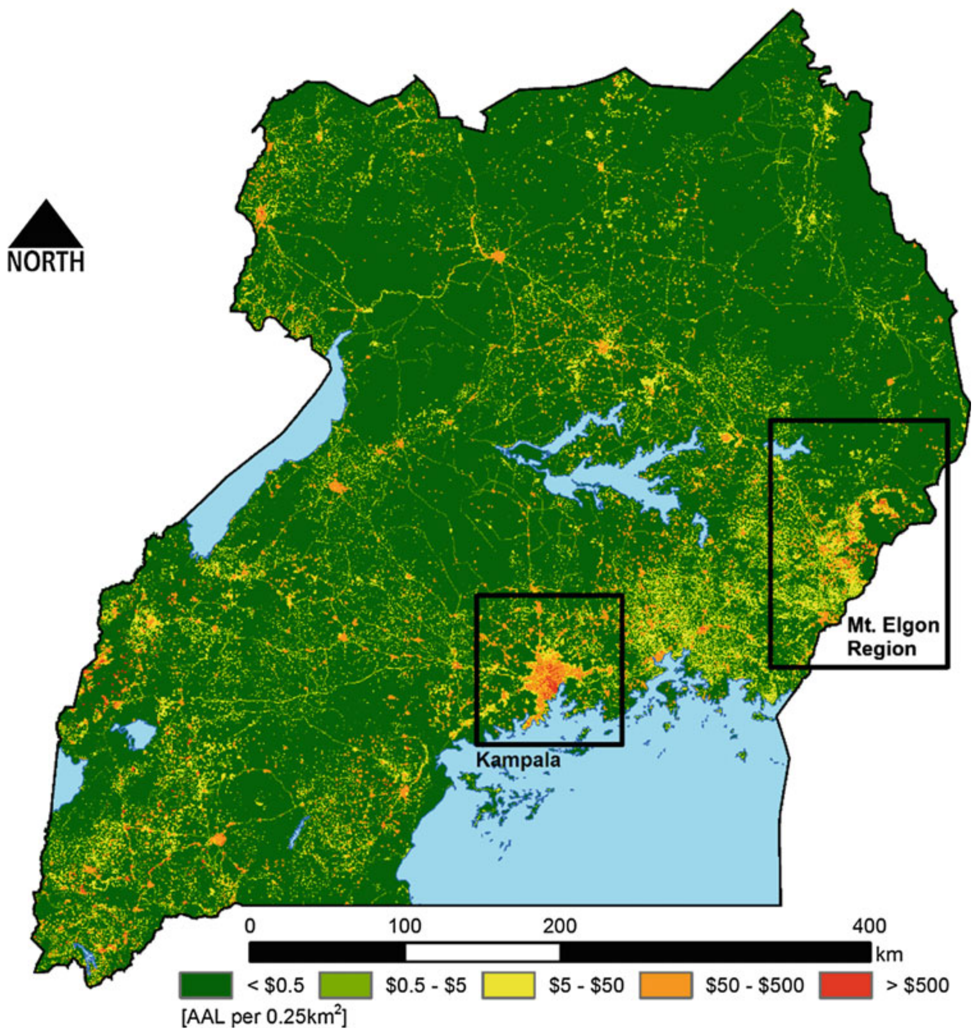

Fig. 2 Landslide risk to the built environment (general building stock, roads and railways) in Uganda

strong components of landslide risk in Sub-Saharan Africa. Landslide hazard, although high in some regions is not always coincident with locations of high exposure. As a result, landslide risk is not always high in areas of high landslide hazard. Similarly, in areas of low landslide hazard, high exposure often results in high landslide risk. For example, the area surrounding Kampala, the capital city of Uganda, is characterised by areas predominantly classified as landslide hazard class B, with some areas of hazard class C. This indicates that this urban environment is not strongly exposed to landslides (nor is it colloquially associated with landslide hazards). However, the consequences should a landslide occur are substantial due to the concentration and value of buildings and roads. By comparison, the foot-slopes of Mount Elgon carry a much greater landslide hazard, however the exposed quantity and rebuild value of the built environment in this area is significantly lower (than in Kampala), resulting in comparable levels of landslide risk and AAL. Kampala and the Mount Elgon region are highlighted on Figs. 1 and 2.

Conclusions

Widely available global datasets were used in conjunction with project-specific regional scale exposure assessments and expert elicitation, to derive estimated landslide hazard and risk assessments for the identification of regional variations in landslide interactions with the built environment in Sub-Saharan Africa.

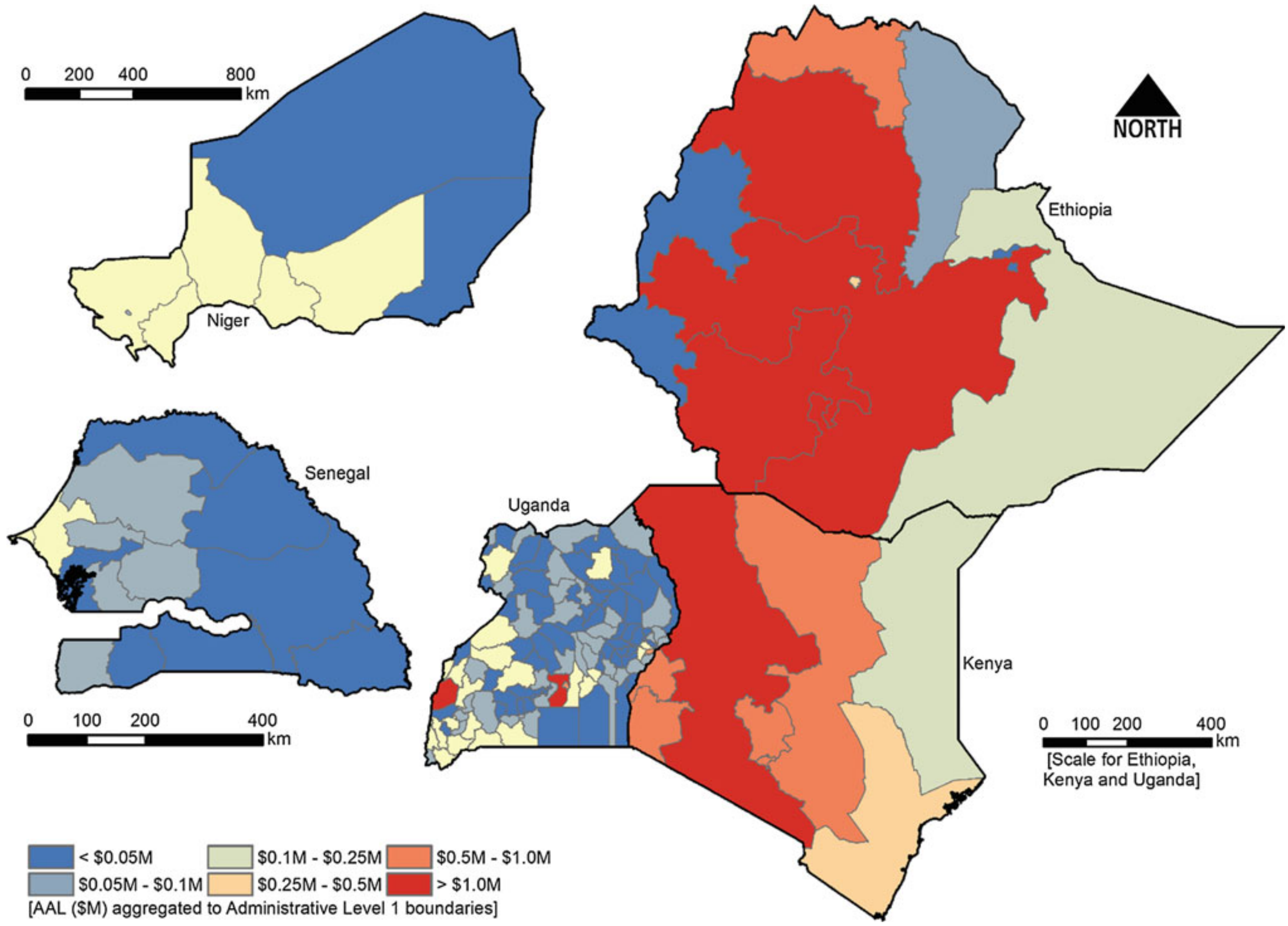

Fig. 3 Landslide risk to the built environment (general building stock, roads and railways) for Ethiopia, Kenya, Uganda, Niger and Senegal, aggregated to Administrative Level 1 boundaries. Niger and Senegal are not shown in correct location

Landslides pose a significant threat to the built environment in the eastern parts of Sub-Saharan Africa due to a combination of high landslide hazard and high vulnerability of exposed assets. Exposure and vulnerability, not hazard however are interpreted to be the key drivers of risk in the Sub-Saharan region of Africa, as illustrated by comparable estimates of expected annual losses to the built environment for low landslide hazard areas in Kampala and for high landslide hazard areas on the foot slopes of Mount Elgon. In Niger and Senegal, landslides pose a less significant threat to the built environment, with estimates of expected annual losses of <$1 M.

Acknowledgements This project was funded by the World Bank and the Global Facility for Disaster Reduction and Recovery. Exposure data was provided by a consortium comprising ImageCat Inc., CIESIN, University of Colorado and SecondMuse under a related project administered by the GFDRR. PGA_{500} data was provided by a consortium comprising Risk Engineering and Design (RED) and Evaluacion de Riesgos Naturales (ERN) under a related project administered by the GFDRR.

Dijkstra and Jordan publish with permission of the Executive Director, British Geological Survey (NERC).

References

Abebe B, Dramis F, Fubelli G, Umer M, Asrat A (2010) Landslides in the Ethiopian highlands and the Rift margins. J Afr Earth Sc 56:131–138

Ayalew L (1999) The effect of seasonal rainfall on landslides in the highlands of Ethiopia. Bull Eng Geol Env 58(1):9–19

Ayalew L, Yamagishi H (2004) Slope failures in the Blue Nile basin, as seen from landscape evolution perspective. Geomorphology 57 (1):95–116

Ayalew L, Moeller D, Reik G (2009) Geotechnical aspects and stability of road cuts in the Blue Nile Basin Ethiopia. Geotech Geol Eng 27 (6):713–728

Beyene F, Busch W, Knospe S, Ayalew L (2012). Heavy rainfall-induced landslide detection from very high resolution multi-aspect TerraSAR-X images in Dessie, Ethiopia. In: Geoscience and Remote Sensing Symposium (IGARSS), 2012 IEEE International, pp 3014–3017

Broothaerts N, Kissi E, Poesen J, Van Rompaey A, Getahun K, Van Ranst E, Diels J (2012) Spatial patterns, causes and consequences of landslides in the Gilgel Gibe catchment, SW Ethiopia. CATENA 97:127–136

Corominas J, van Westen C, Frattini P, Cascini L, Malet J-P, Fotopoulou S, Catani F, Van Den Eeckhaut M, Mavrouli O, Agliardi F, Pitilakis K, Winter MG, Pastor M, Ferlisi S, Tofani V, Hervas J, Smith JT (2014) Recommendations for the quantitative analysis of landslide risk. Bull Eng Geol Environ 73:209–263

Du J, Nadim F, Lacasse S (2013) Quantitative vulnerability estimation for individual landslides. In: Proceedings of the 18th international conference on soil mechanics and geotechnical engineering, Paris, pp 2181–2184

Fall M, Azzam R, Chicgoua N (2006a) Landslide danger assessment of large-scale natural slopes—a GIS based approach. Paper 104. IAEG 2006 Engineering Geology for Tomorrow's Cities: 10th international congress of the international association for engineering geology and the environment, 6–10 Sept 2006, Nottingham [online]. Available online: www.iaeg2006.geolsoc.org.uk. Accessed 07 Aus 2016

Fall M, Azzam R, Noubactep C (2006b) A multi-method approach to study the stability of natural slopes and landslide susceptibility mapping. Eng Geol 82(4):241–263

Fubelli G, Guida D, Cestari A, Dramis F (2013) Landslide hazard and risk in the Dessie Town area (Ethiopia). Landslide Science and Practice 6:357–362

Horton P, Jaboyedoff M, Bardou E (2008) Debris flow susceptibility mapping at a regional scale. In: Locat J, Perret D, Turmel D, Demers D, Leroueil S (eds) Proceedings of the 4th Canadian conference on Geohazards: from causes to management, Presse de l'Universite Laval, Quebec, pp 399–406

Jacobs L, Dewitte O, Poesen J, Sekajugo J, Maes J, Mertens K, Kervyn M (2015) A first landslide inventory in the Rwenzori Mountains, Uganda. In EGU General Assembly Conference Abstracts (vol 17, p 5997)

Kitutu M (2010) Landslide occurrences in the hilly areas of Bududa district in eastern Uganda and their causes. Doctoral dissertation, Makerere University, 106p

Kitutu M Goretti, Muwanga A, Poesen J, Deckers JA (2011) Farmer's perception on landslide occurrences in Bududa District, Eastern Uganda. Afr J Agric Res 6(1):7–18

Knapen A, Kitutu M Goretti, Poesen J, Breugelmans W, Deckers J, Muwanga A (2006) Landslides in a densely populated county at the footslopes of Mount Elgon (Uganda): characteristics and causal factors. Geomorphology 73(1):149–165

Lee EM, Jones DKC (2004) Landslide risk assessment. Thomas Telford Ltd, London

Maina-Gichaba C, Kipseba EK, Masibo M (2013) Overview of landslide occurrences in Kenya: causes, mitigation, and challenges

Mastrandrea MD, Field CB, Stocker TF, Edenhofer O, Ebi KL, Frame DJ, Held H, Kriegler E, Mach KJ, Matschoss PR, Plattner GK, Yohe GW, Zwiers FW (2010) Guidance note for lead authors of the IPCC fifth assessment report on consistent treatment of uncertainties. Intergovernmental Panel on Climate Change (IPCC). Available online: http://www.ipcc.ch

Mavrouli O, Fotopoulou S, Pitilakis K, Zuccaro G, Corominas J, Santo A, Cacace F, De Gregorio D, Di Crescenzo G, Foerster E, Ulrich T (2014) Vulnerability assessment for reinforced concrete buildings exposed to landslides. Bull Eng Geol Environ 73:265–289

Meten M, PrakashBhandary N, Yatabe R (2015) Effect of landslide factor combinations on the prediction accuracy of landslide susceptibility maps in the Blue Nile Gorge of Central Ethiopia. Geoenvironmental Disasters 2(1):1–17

Musinguzi M, Asiimwe I (2014) Application of geospatial tools for landslide hazard assessment for Uganda. S Afr J Geomatics 3 (3):302–314

Nadim F, Kjekstad O, Domaas U, Rafat R, Peduzzi P (2006). Global landslides risk case study. In: Arnold et al (ed) Natural disaster hotspots; case studies. Disaster risk management series. The World Bank, Washington, pp 21–64

Nadim F, Jaedicke C, Smebye, H, Kalsnes B (2013) Assessment of global landslide hazard hotspots. In: Sassa K, Rouhban B, Briceno S, McSaveney M, He B (eds) Landslides: global risk preparedness, pp 59–71

NEMA (2007). Uganda: National State of the Environment Report 2007, 357p

Ngecu WM, Ichang'i DW (1999) The environmental impact of landslides on the population living on the eastern footslopes of the Aberdare ranges in Kenya: a case study of Maringa Village landslide. Environ Geol 38(3):259–264

Temesgen B, Mohammed MU, Korme T (2001) Natural hazard assessment using GIS and remote sensing methods, with particular reference to the landslides in the Wondogenet area, Ethiopia. Phys Chem Earth Part C 26(9):665–675

Terra Daily (2010) Uganda plans to relocate 500,000 at risk of landslides: minister. Available online: http://www.terradaily.com/reports/. Hosted by Terra Daily. Accessed 20 Mar 2015

Van Den Eeckhaut M, Poesen J, Govers G, Verstraeten G, Demoulin A (2007) Characteristics of the size distribution of recent and historical landslides in a populated hilly region. Earth and Planet Sci Lett 256:588–603

Van Den Eeckhaut M, Moeyersons J, Nyssen J, Abraha A, Poesen J, Haile M, Deckers J (2009) Spatial patterns of old, deep-seated landslides: a case-study in the Northern Ethiopian highlands. Geomorphology 105(3):239–252

Vařilová Z, Kropáček J, Zvelebil J, Šťastný M, Vilímek V (2015) Reactivation of mass movements in Dessie graben, the example of an active landslide area in the Ethiopian Highlands. Landslides 12 (5):985–996

Wang HG, Montoliu-Munoz M, Gueye NFD (2009) Preparing to manage natural hazards and climate change risks in Dakar, Senegal—a spatial and institutional approach. Pilot study report, World Bank, p 101p

Springer

http://www.springer.com/978-3-319-53482-4

Advancing Culture of Living with Landslides
Volume 5 Landslides in Different Environments
Mikoš, M.; Vilímek, V.; Yin, Y.; Sassa, K. (Eds.)
2017, XXI, 557 p. 382 illus., 358 illus. in color.,
Hardcover
ISBN: 978-3-319-53482-4