Adopting rainfall threshold analysis for landslides in Central Africa using satellite rainfall estimates

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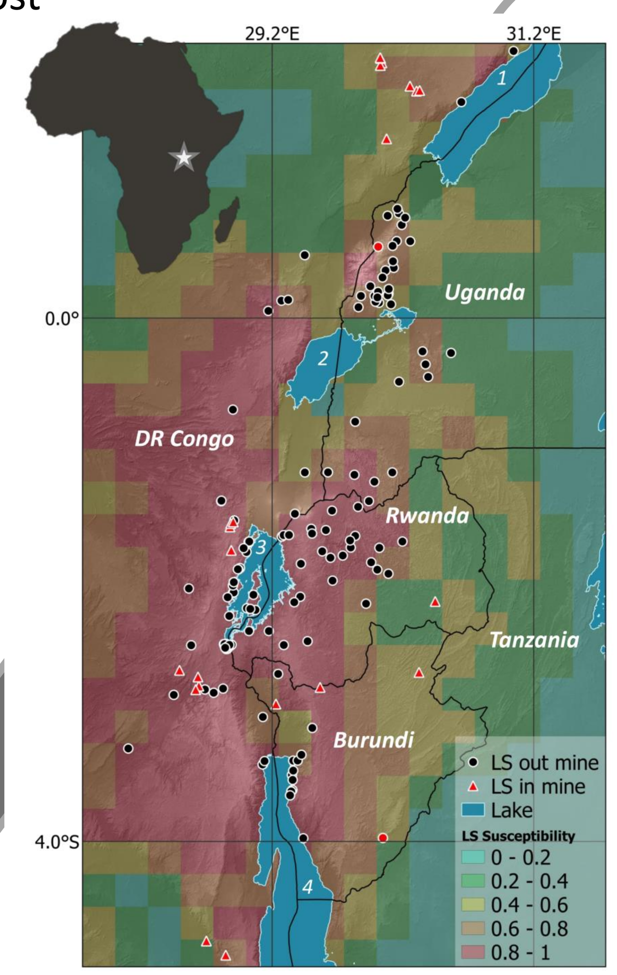
CONTEXT

- Rainfall thresholds are the most used instrument in **landslide hazard** assessment and early warning tools
- Improvements have been made towards **more reproducible techniques** for the identification of triggering conditions for landsliding, and **standardized threshold calibrating** techniques
- The now well-established rainfall intensity or event – duration thresholds for landsliding suffer from several **limitations**
- No threshold mapping involving **landslide susceptibility** as a proxy integrating the causative ground factors has been proposed to date beyond local-scale physically-based models
- Rainfall threshold research is almost **inexistent in Africa**, related to the dearth of data on timing and location of landslides

OBJECTIVES

- **Improve the frequentist method** for rainfall threshold definition
- Account for **more than solely the aspect of rainfall** characteristics in the threshold analysis
- Make the approach applicable in regions with limited rainfall gauge data
- Provide the first regional rainfall thresholds for landsliding in tropical **Africa**



LANDSLIDES IN THE WESTERN BRANCH OF THE EAST AFRICAN RIFT (WEAR)

Predisposing factors in the WEAR include:

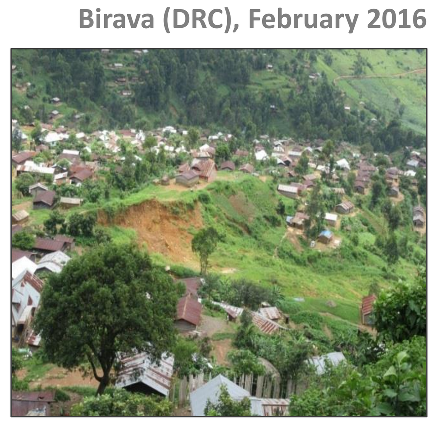
- High seismicity
- Intense rainfall
- Deeply weathered substrates
- Steep slopes

rendering the area highly prone to landsliding

- A **landslide inventory** was compiled, comprising:
  - 174 landslide events with known location and date of occurrence;
  - occurred between 2001 and 2018


Nyabibwe (DRC), June 2016

Birava (DRC), February 2016


Nyabibwe (DRC), October 2012


Bukavu (DRC), June 2016


Tara (DRC), August 2017

CAUSE-TRIGGER FRAMEWORK

- We adopt the suggestion of Bogaard and Greco (2018) who advocate **a combination of meteorological and hydrological conditions** into a 'trigger-cause' framework for the threshold definition for landslides
- In this study we distribute the influence of hydrological conditions between
  - **trigger**, by an elaborate *AR* function that aims to reflect the hydrology of an empirical average soil, and
  - **cause**, by capturing in the susceptibility the spatial variations of hydrological conditions expected from the distribution of the causative ground factors.

LANDSLIDE CAUSE

- **Regional ground conditions** affect the meteorological conditions required for landsliding
- We adopt here the landslide susceptibility model from Broeckx et al. (2018), produced through logistic regression (4:1 L/NL ratio) including **topography, lithology, peak ground acceleration and precipitation**
- This avoids problems of data subsetting in regions with **limited data** when regionalizing the input data according to individual predisposing factors

MODIFIED FREQUENTIST APPROACH

for threshold calibration

Here, we propose a new approach of the frequentist method proposed by Brunetti et al. (2010) and Peruccacci et al. (2012) while integrating climatic (AR) and landslide susceptibility (S) factors into a 2D graph, by:

- Quantitatively exploiting the lower parts of the cloud of data points, most meaningful for threshold estimation
- Merging the uncertainty on landslide date with the fit uncertainty in a single error estimation obtained by a bootstrap statistical technique

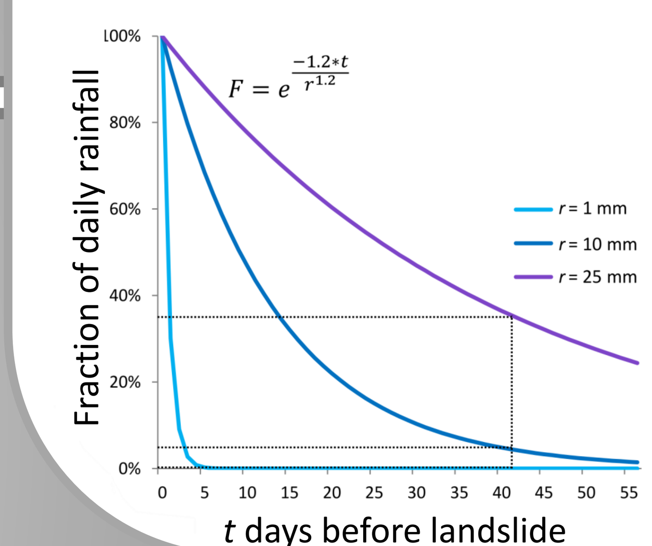
$$AR = (\alpha \pm \Delta\alpha) * S^{(\beta \pm \Delta\beta)}$$

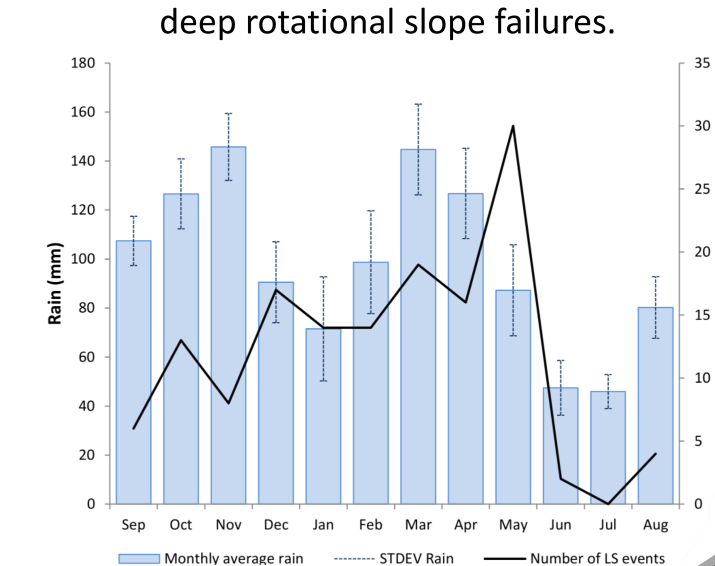
LANDSLIDE TRIGGER

- **Infiltration depth** and, thus, residence time of the rain water in the soil increase with daily rainfall. We take this into account by introducing also daily **satellite rainfall estimates (TMPA 3B42 RT)** r_t in the filter function and expressing **antecedent rainfall** (AR) in the form of an exponential function of time t, over a period empirically fixed to the preceding n days:

$$AR_i = \sum_{k=i}^{i-n} e^{\frac{-a*(t_i-t_k)}{r_k^b}} * r_k$$

- a = 1.2 and b = 1.2 provide decay curves that comply with both a **realistic contrast in residence time** of different rainfall in the soil and the **duration of their effect** on soil moisture
- AR is calculated over a period of **six weeks**. A fairly long period is required because **all landslide types** are included in the data set, including large-scale and deep rotational slope failures.





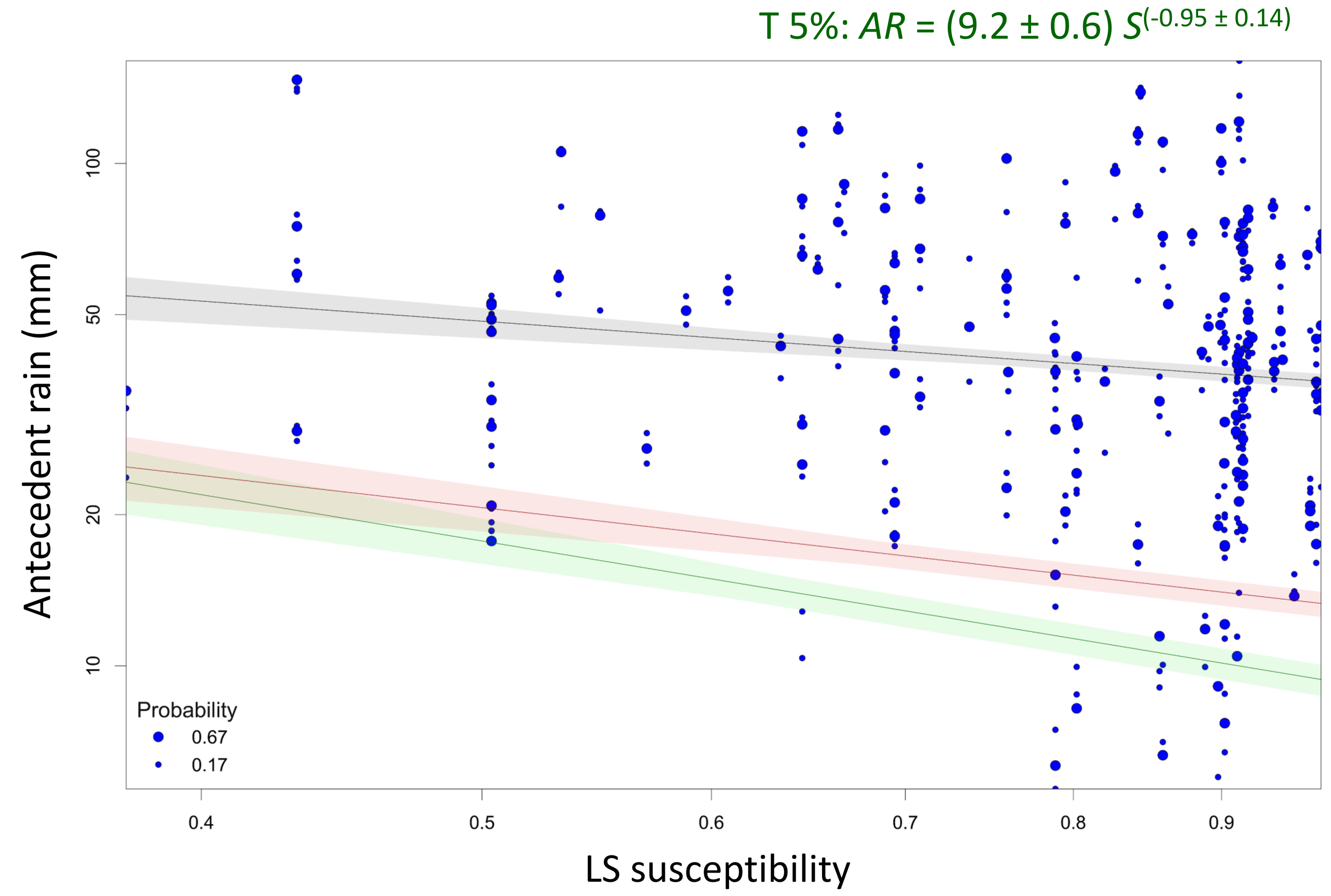
ANTECEDENT RAINFALL THRESHOLDS

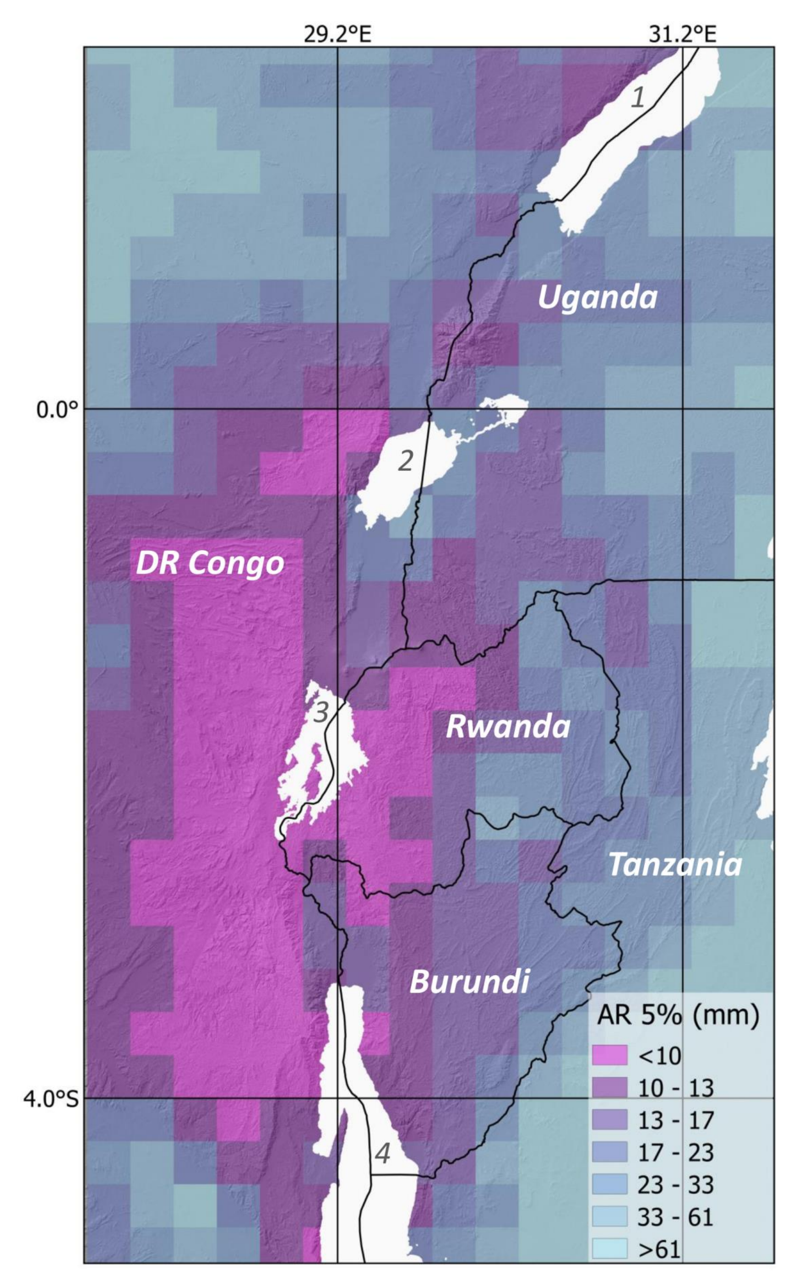
- We identify the **first rainfall thresholds** for landsliding in the western branch of the East African Rift. The obtained AR thresholds are **physically meaningful** and range, without correction for satellite rainfall underestimation, from 9.5 mm to 23.1 mm for an exceedance probability of 5%.
- The applied method has the main advantage of **directly mappable** susceptibility-dependent rainfall thresholds.

$$AR = (36.5 \pm 1.2)\ S^{(-1.41 \pm 0.09)}$$

$$\text{T 10\%: } AR = (13.1 \pm 0.7)\ S^{(-0.66 \pm 0.15)}$$

$$\text{T 5\%: } AR = (9.2 \pm 0.6)\ S^{(-0.95 \pm 0.14)}$$





- A 5% exceedance probability, for instance, means that any landslide occurring in the field has a 0.05 probability of being triggered by an AR value lower than that defined by the threshold curve, with about weighted 5% of the data points effectively lying below the curve

FUTURE WORK

Expected improvements from:

- Regionally-focused susceptibility maps
- Higher resolution Satellite Rainfall data (IMERG)
- Larger landslide database, allowing for:
  - Threshold validation;
  - Distinction of landslide types and hence;
  - Calculation of adapted thresholds

FOR MORE INFORMATION

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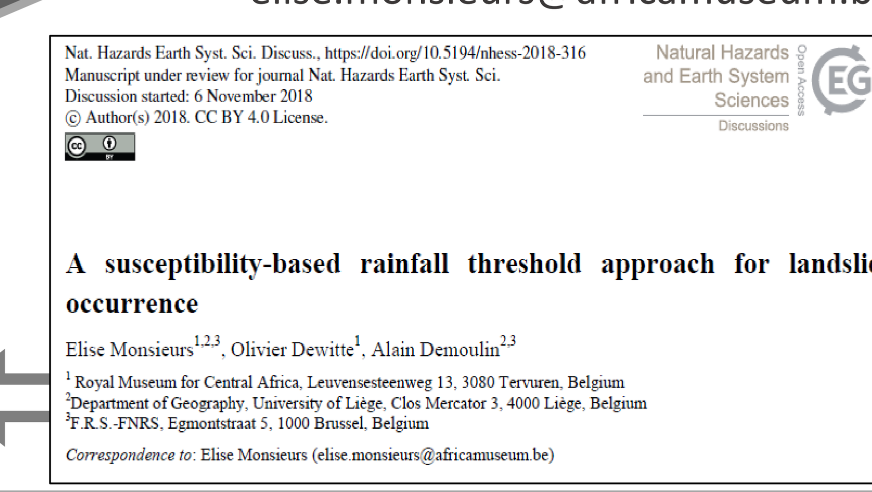
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Natural Hazards and Earth System Sciences Discussions

A susceptibility-based rainfall threshold approach for landslide occurrence

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