Urban growth changes the pulse of a large deep-seated landslide

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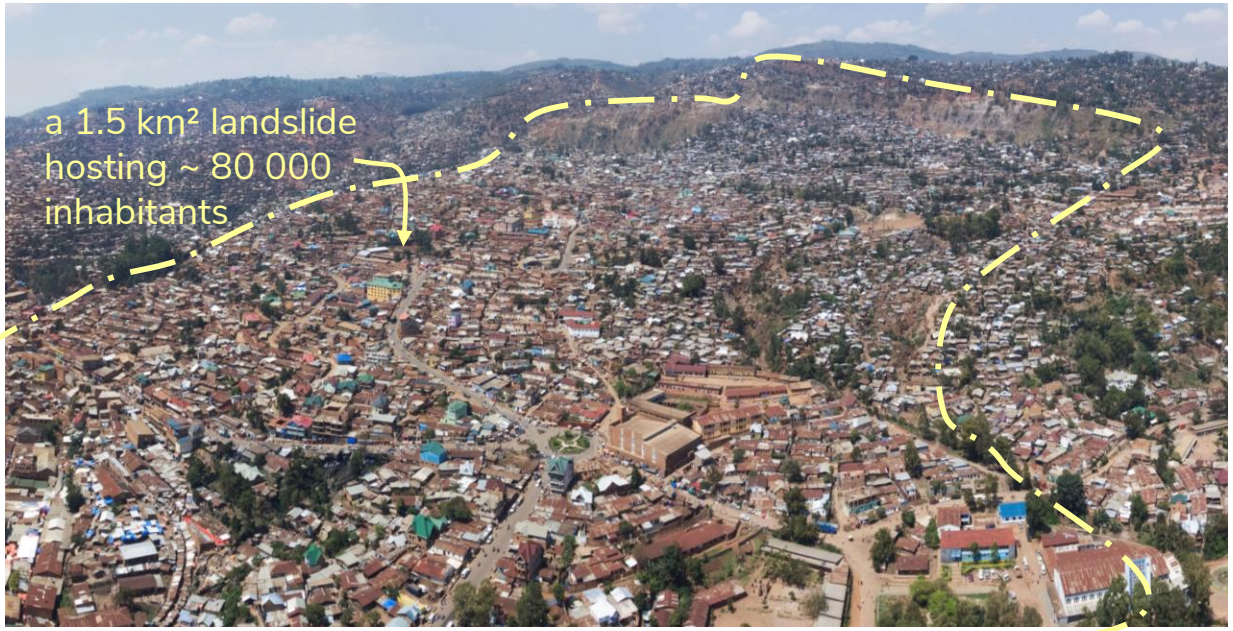
- The behaviour of **slow-moving landslides** is **well described in natural environments** – simplified mechanisms showing that **rainfall-induced changes in pore-water pressure** are principally **regulating their motion**.

- Yet, while hydrologists have long recognized that **urbanisation** has **dramatic impacts** on **catchment hydrology**, very little is known on the **influence of urbanisation** on landslide behaviour.

- Aiming at studying how landslides respond to urbanisation, we here present an analysis of the dynamics of a **slow-moving deep-seated landslide** sited in the **tropical environments** of the rapidly expanding city of Bukavu (eastern DR Congo).

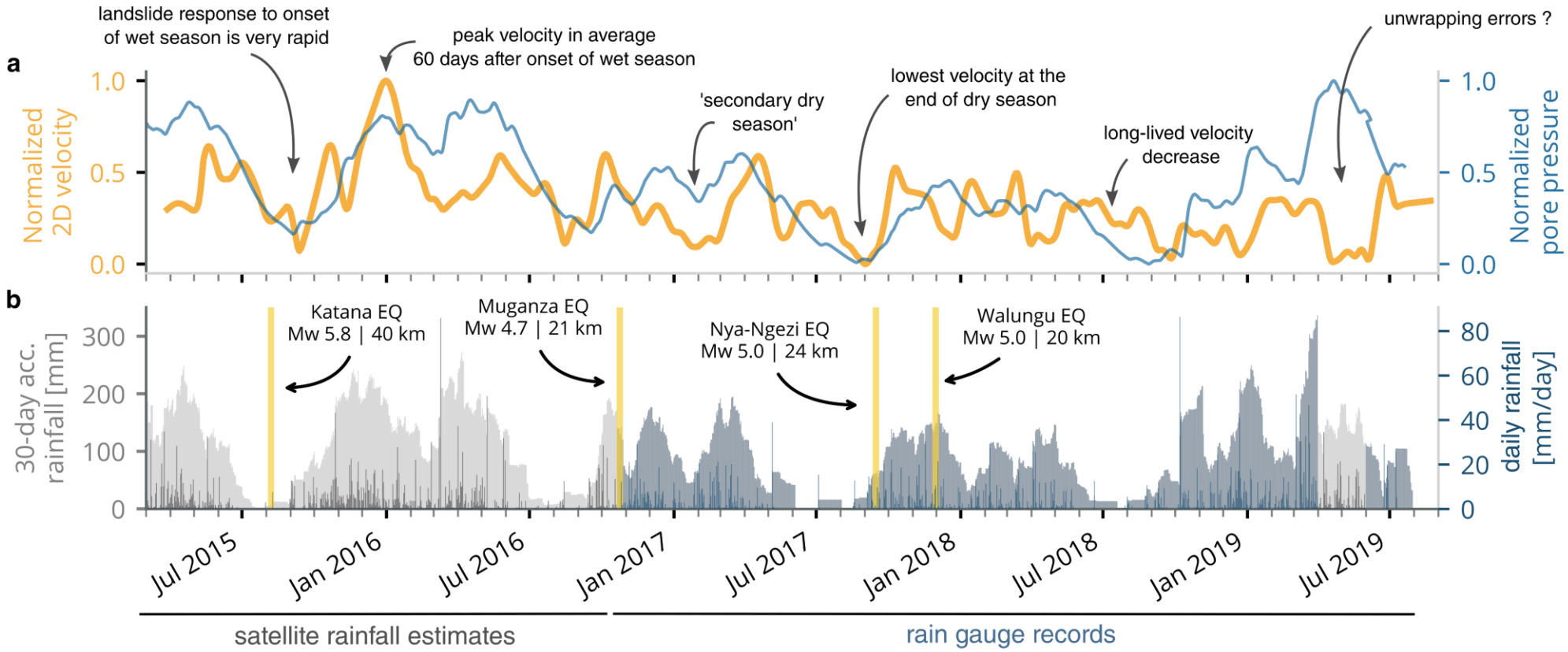
Most studies of landslides behaviour focus on landslides sited in natural environments



Bukavu, an example of rapidly expanding city in a landslide-prone tropical environment

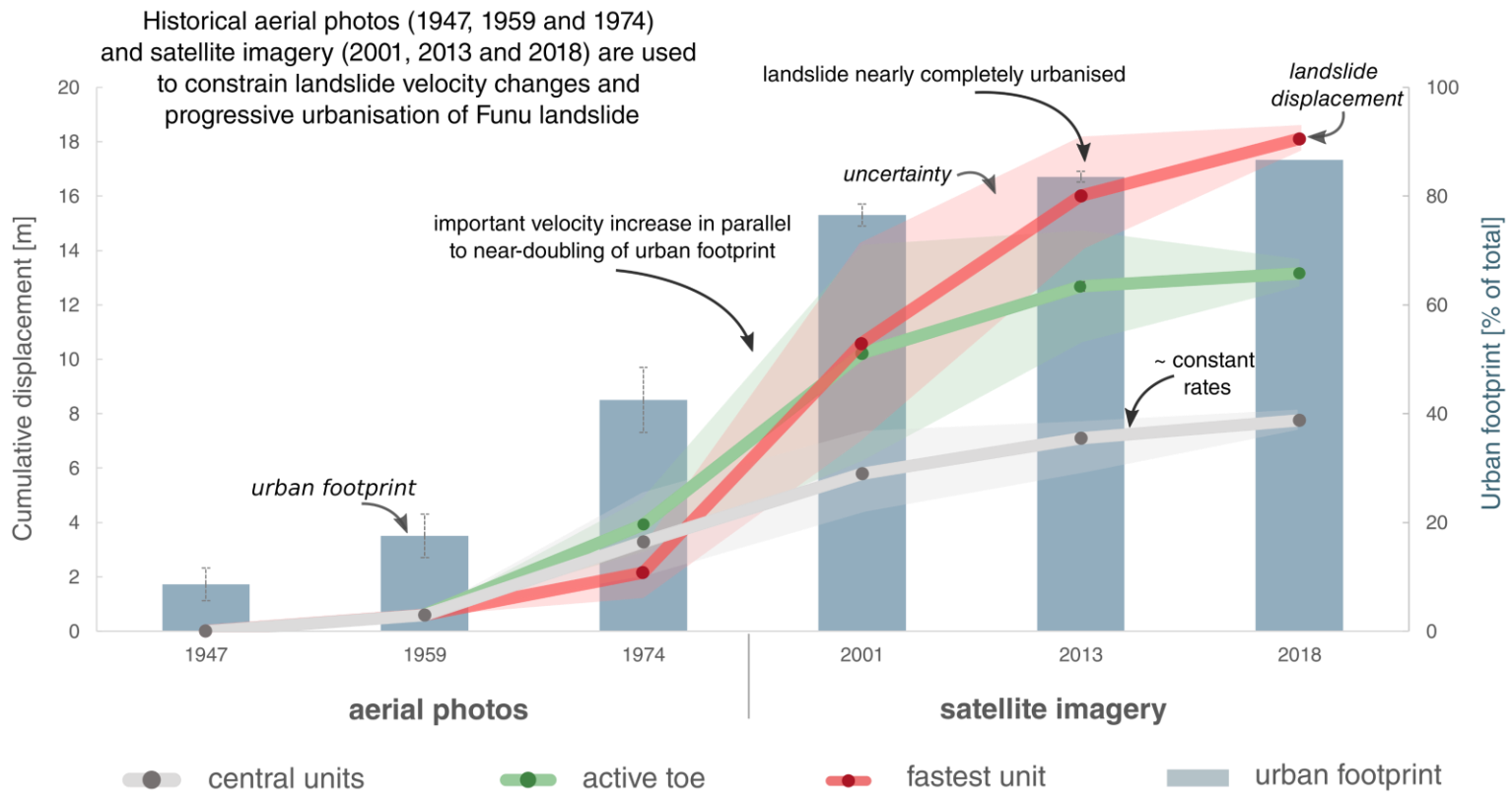
SUMMARY - I

- building on **4.5 years of very dense InSAR times series**, we show that **changes in slope velocity** are closely tied to **changes in slope pore-water pressure**. Without being able to unambiguously disentangle the effects of different environmental factors acting on the slope, we show that the **impact of urbanisation** on slope **groundwater circulation** and **saturation may explain** the **unusual landslide behavior**.

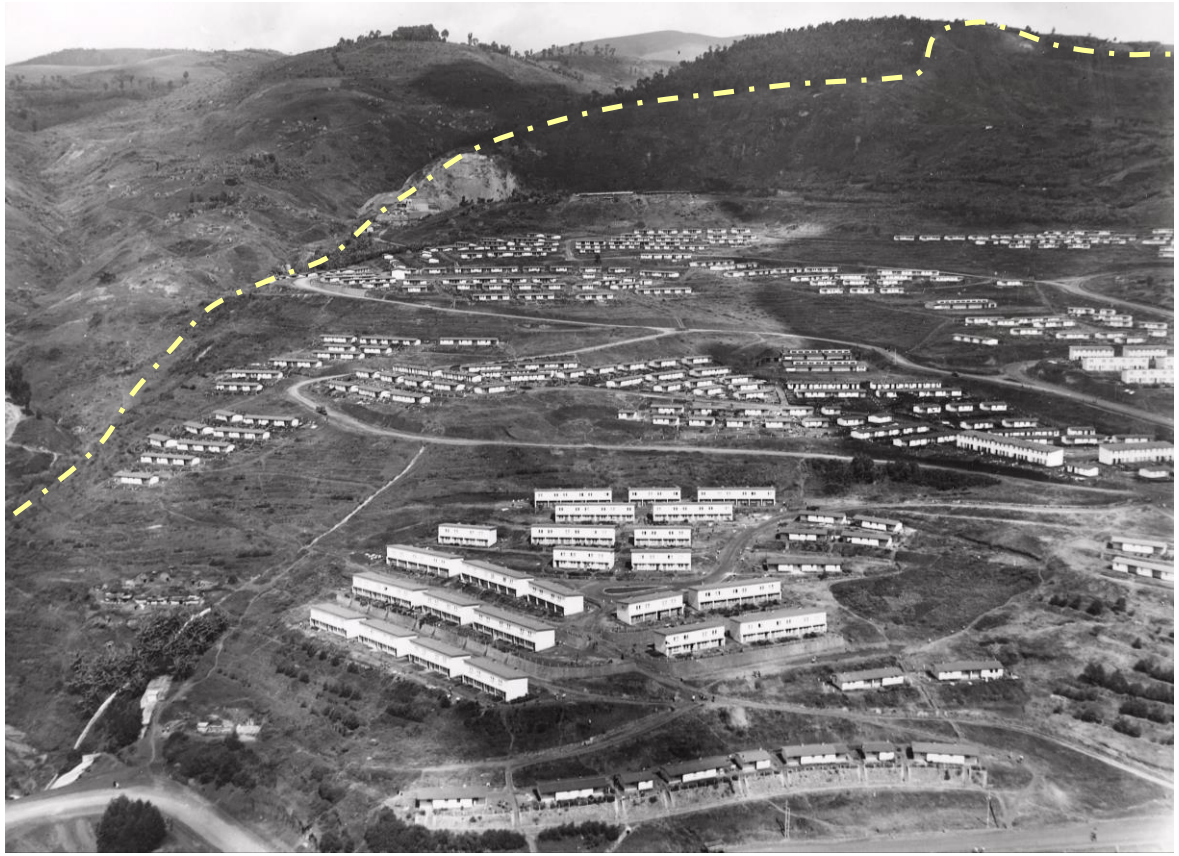


SUMMARY - II

- looking back at **hillslope changes over the last 70 years**, we show the timing of the acceleration of a large landslide unit to **coincides with the intensification of the informal urbanisation** of the hillslope.



SUMMARY - III



Funu landslide in 1959

Funu landslide in 2018

Our results draw attention to the fact **that urbanisation can interfere with the natural behaviour** of long-lived, deep-seated landslides. As **hillslopes of the world's cities are being urbanised at accelerating paces**, we believe that such studies are needed to improve **our understanding of how anthropogenic activity influence surface process** and **landscape evolution**, as well as ensure the valid **evaluation of landslide hazard** and optimisation of **mitigation strategies**.

OVERVIEW

- environmental context : the Kivu Rift
- study of seasonal landslide controls from SAR interferometry (MSBAS 3D)
- analysis of long-term hillslope changes - urban development and slope instability

Kivu Rift

Tropics

- intense rainfall events
- deep weathering

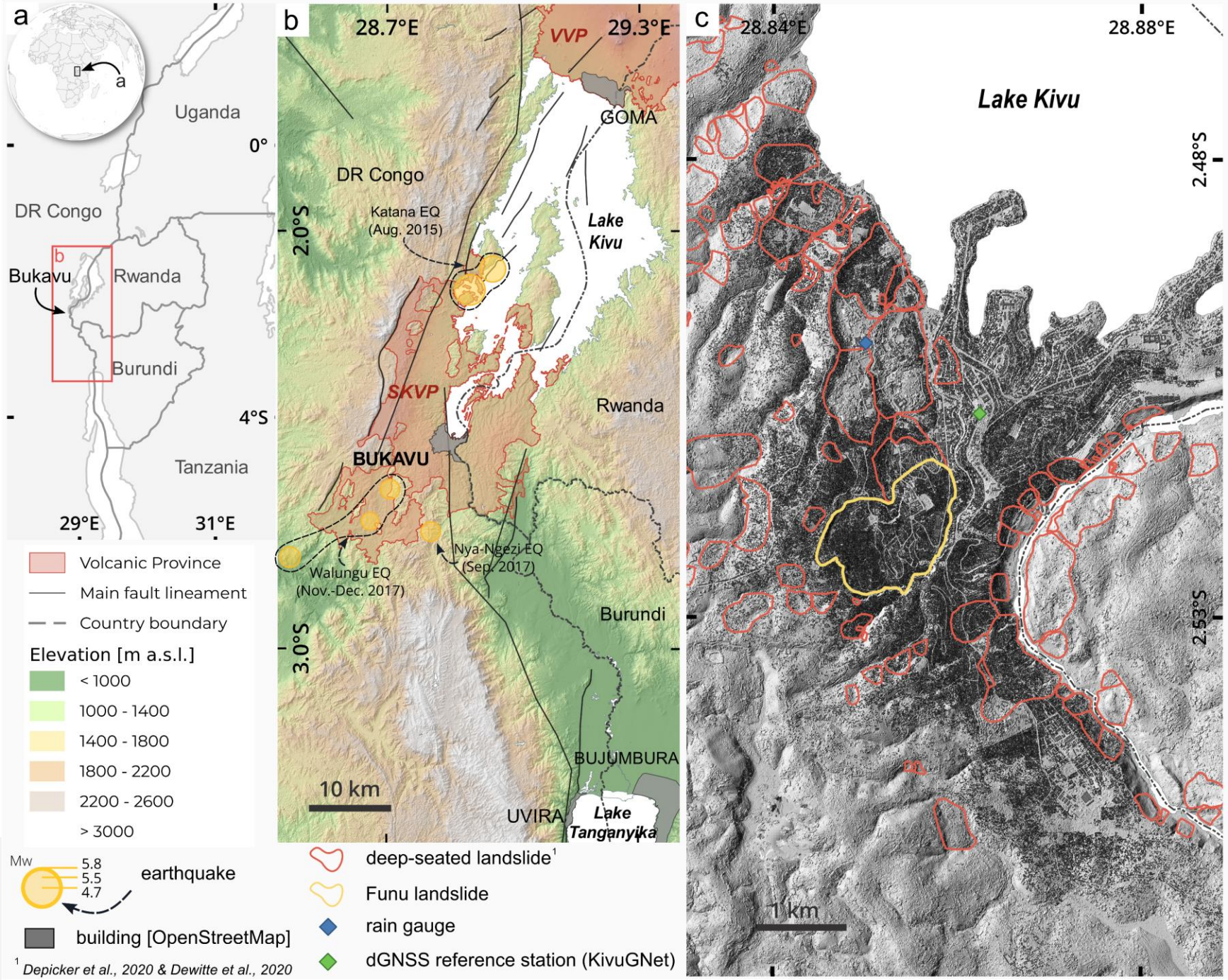
East African Rift System

- steep topography
- moderate seismicity
- heavily faulted

Bukavu (DR Congo)

- old basaltic province
- high population pressure
- context of data scarcity

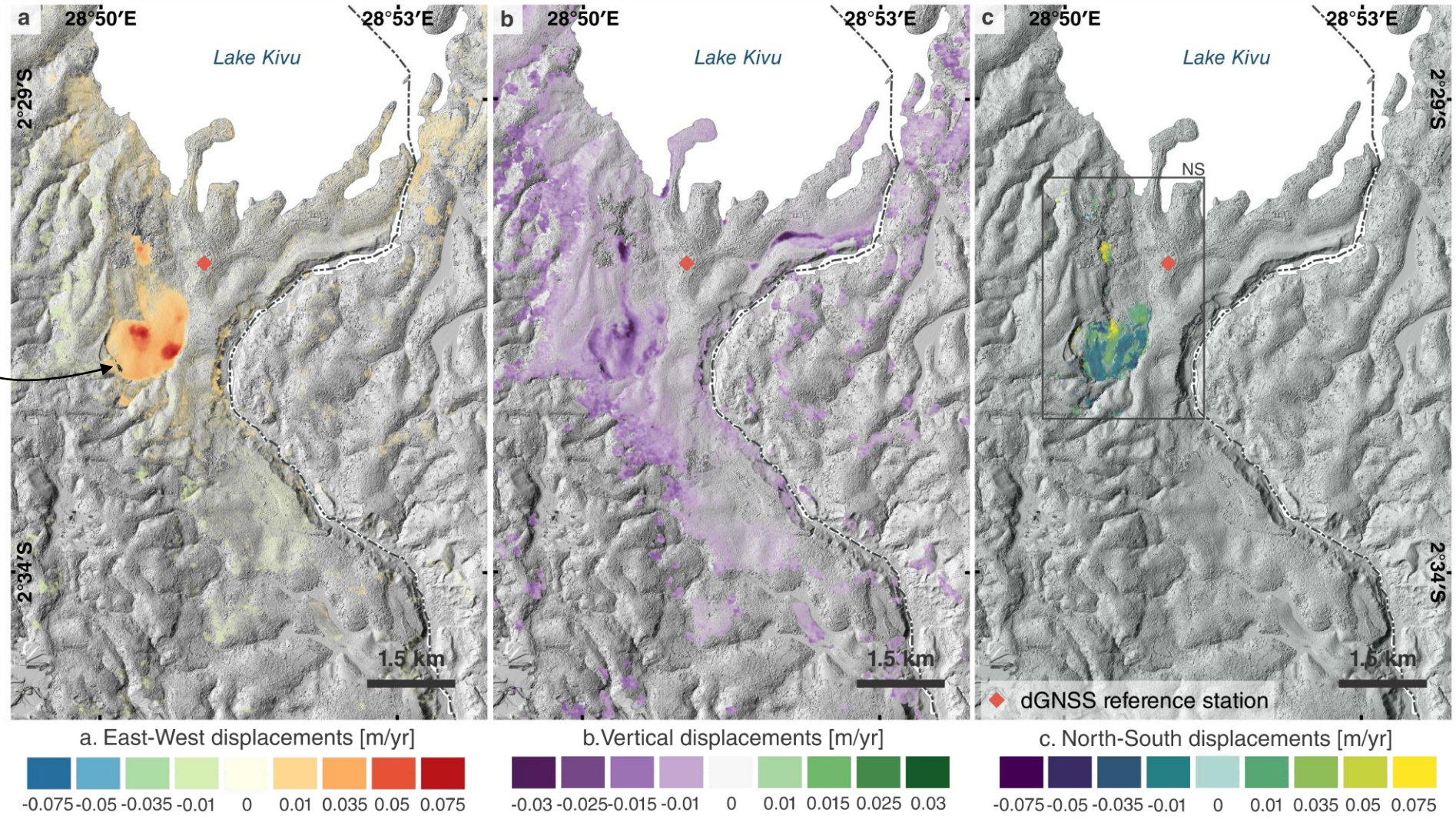
Highly landslide-prone and rapidly expanding city -> today one-third of the city is built on deep-seated landslides



Seasonal controls on urban landslide

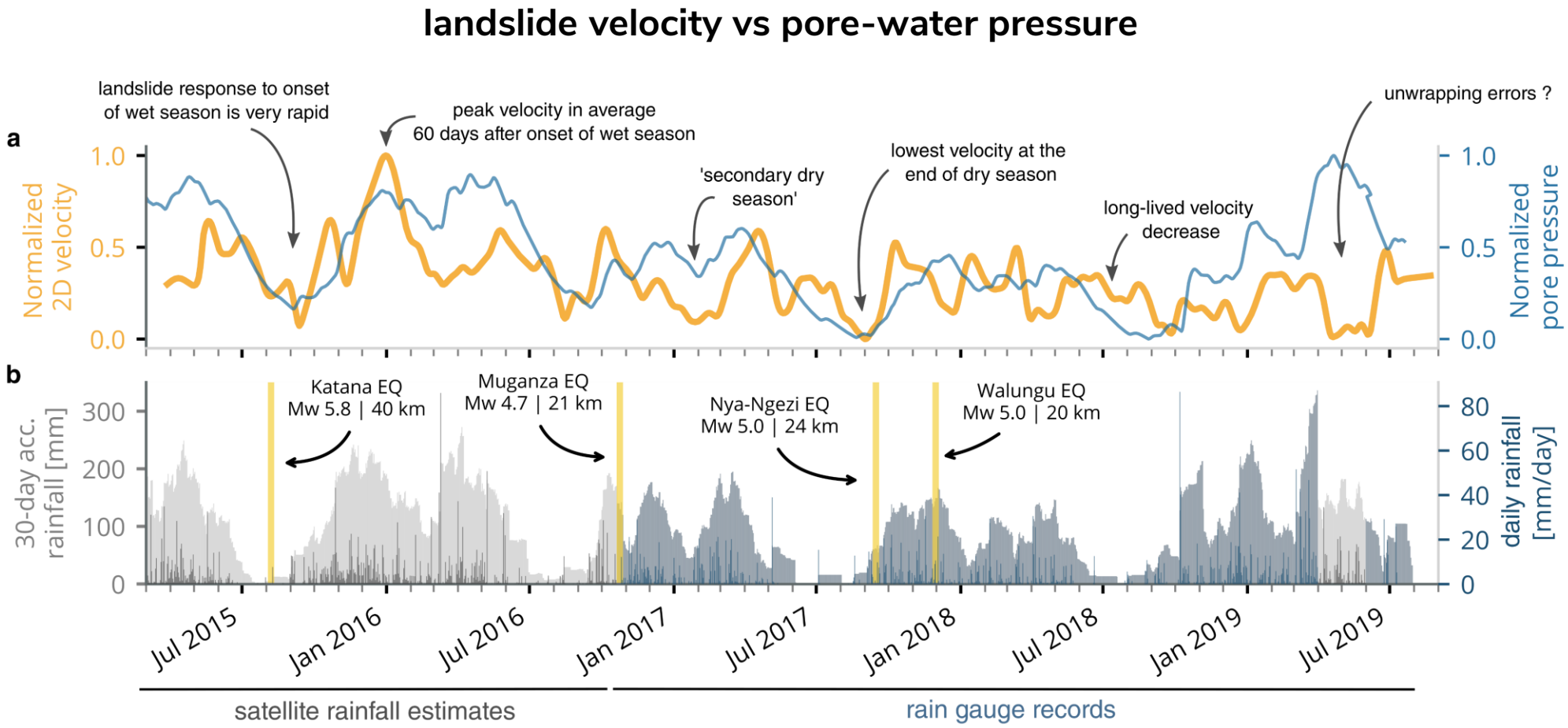
SAR interferometry to measure 3D surface displacements with a sub-weekly resolution over 4.5 years

Funu landslide



For more info on MSBAS 3D see Samsonov et al. 2020, *Engineering Geology*

Seasonal controls on urban landslide

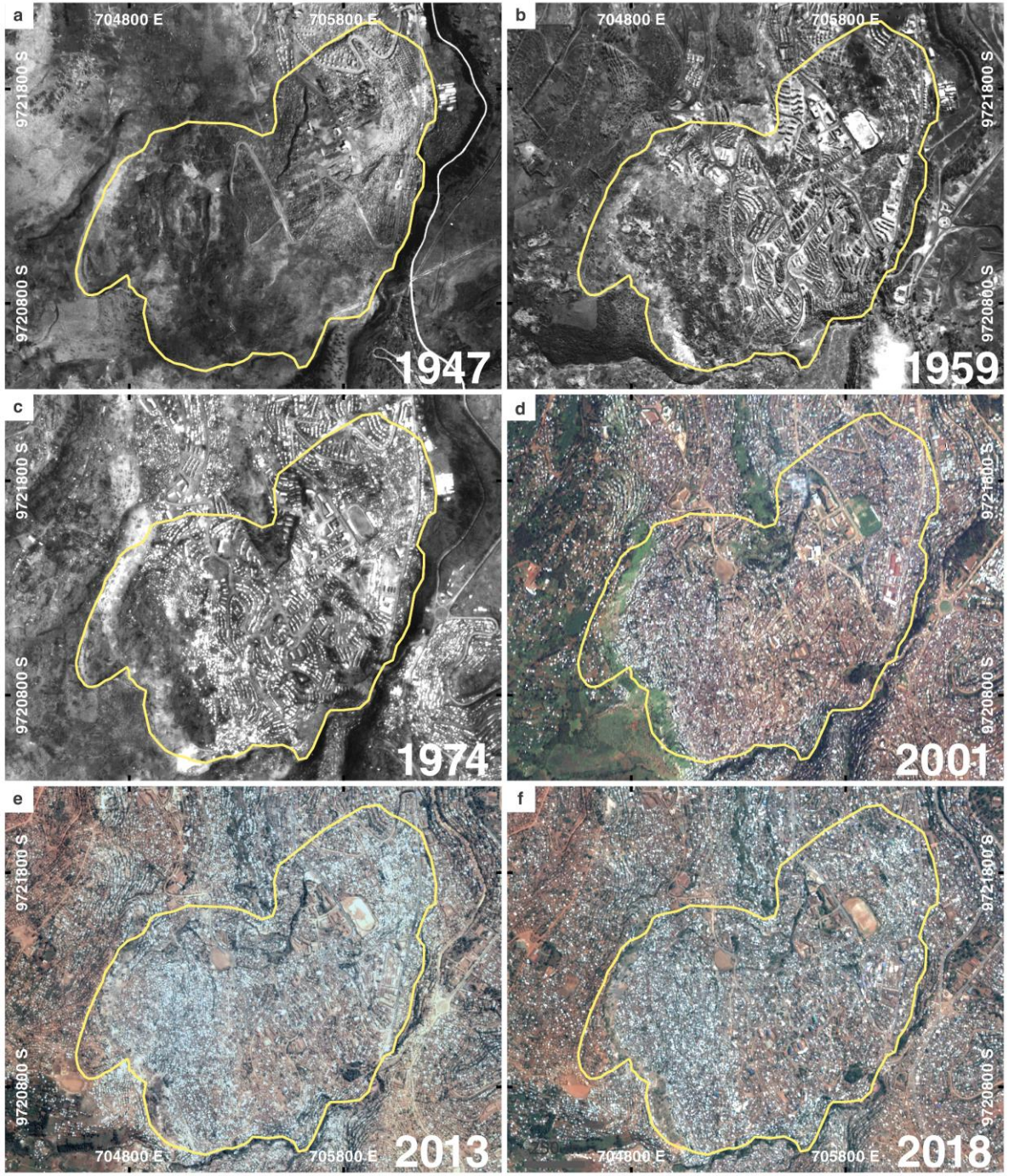


closely tied relationship between slope velocity and pore-water pressure changes indicating that near-surface groundwater flows play a key role in the week-to-week kinematic ; no apparent effect of nearby earthquakes

Long-term hillslope changes

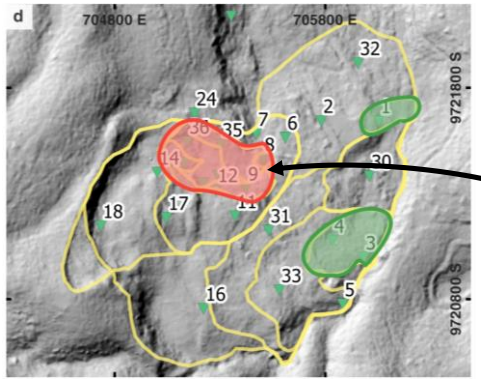
Progressive hillslope urbanisation

- only the landslide toe was urbanised in 1947
- intensification of informal urbanisation in the ’90s alongside rural-urban migration driven by regional conflicts
- from early 2000, 80 % of the landslide is urbanised – mostly light, informal dwellings
- distribution and drainage systems become more and more inadequate and subject to leaks



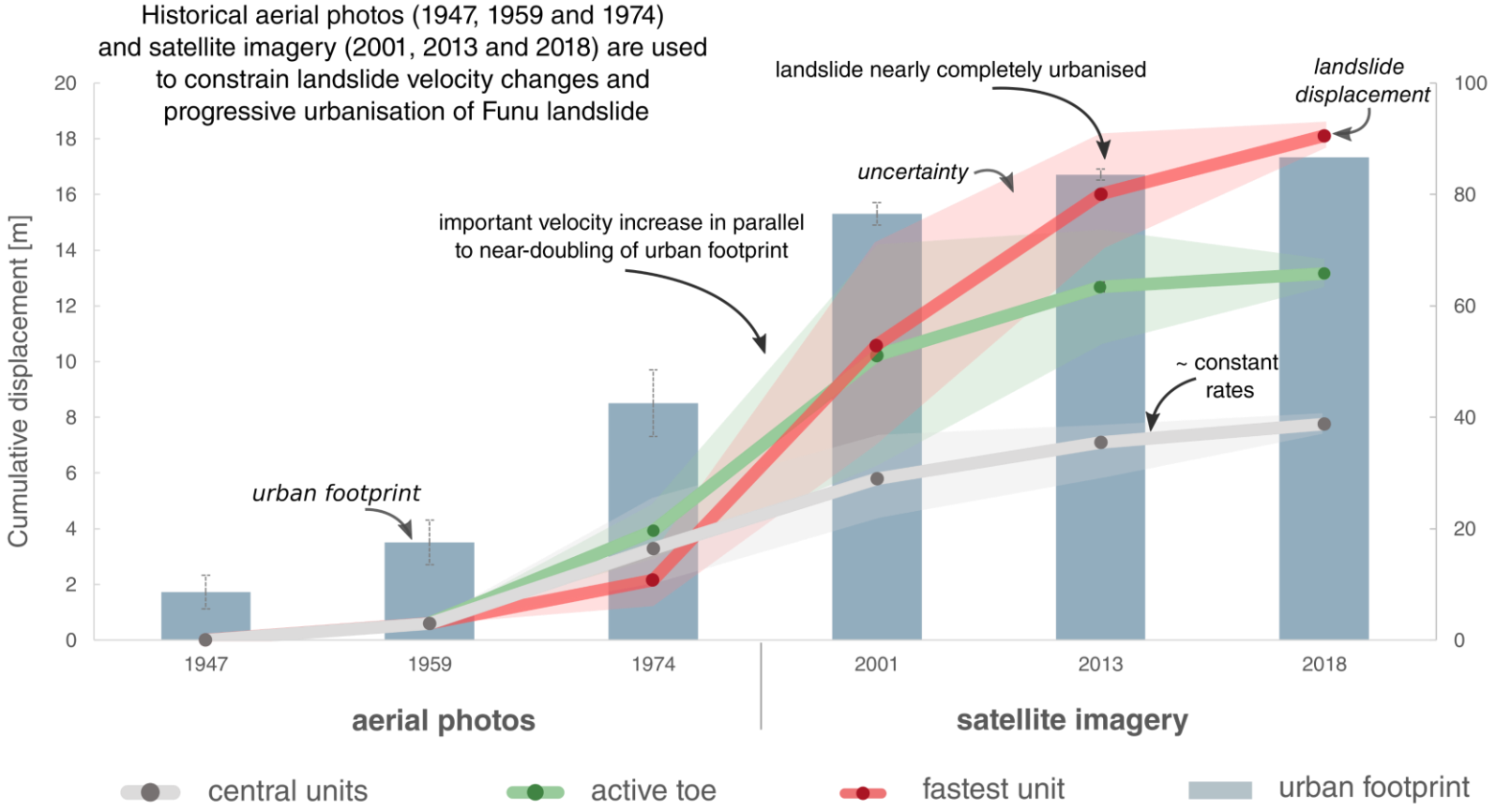
Long-term hillslope changes

- important velocity increase for a zone of the landslide between 1974 and 2001
- this period corresponds to a time of intensification of informal urbanisation
- stresses from deformation and mismanagement of water distribution system led to rupture of water pipe within slope and the formation of deep gullies



fastest unit

landslide displacement vs urban development



urbanisation and landslide behaviour

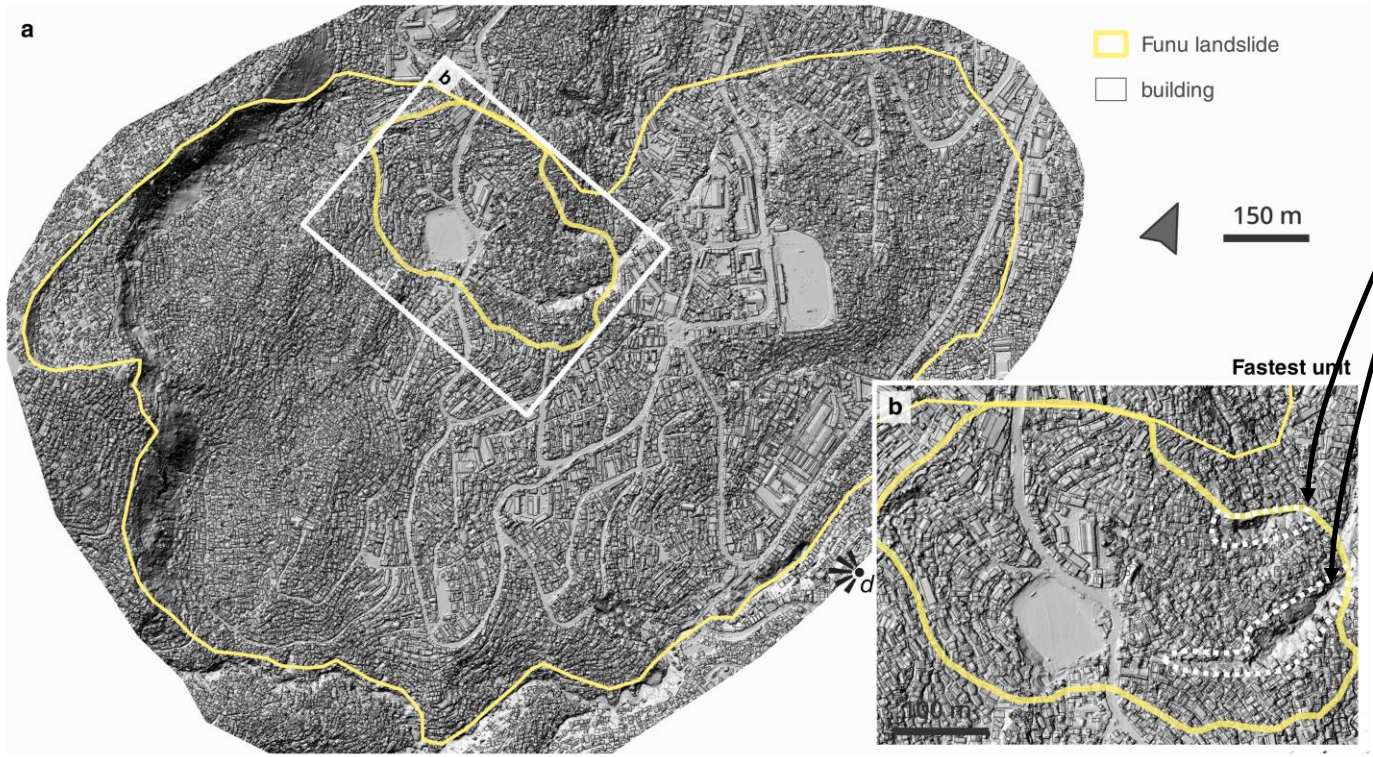
Urbanisation influences slope hydrology

- modifies how and where water infiltrates
- changes sources and location of slope recharge
- involves drastic and extensive reorganisations of surface and subsurface infiltration pathways
- water distribution systems bring water from outside the catchment

→ urbanisation impacts slope **groundwater circulation** and **saturation**

→ considering their strong controls on **hillslope stress state**, the **influence of urbanisation** on landslide dynamic is to be stressed

deep gullies formed following a pipe rupture



many pipes still date from before 1960

Conclusions

- Our results draw attention to the fact **that urbanisation can interfere with the natural behaviour** of long-lived, deep-seated landslides.
- As **hillslopes of the world's cities are being urbanised at accelerating paces**, we believe such studies are need to improve **our understanding of how anthropogenic activity influence surface process** and **landscape evolution**, as well as ensuring a valid **evaluation of landslide hazard** and optimisation of **mitigation strategies**.

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