

The Effect of Climate Change on Landslides

Nathasya Christien

Based on Crozier (2010)

Today's Relevance: Recent news from Indonesia



Landslide disaster in North Sumatra
(December 6, 2025)

Source: Antara News

- Cyclone-induced floods and landslides impacted Sumatra.

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- Cyclone-induced floods and landslides impacted Sumatra.
- Public has pointed out how this disaster is also human-induced.

Influential Papers on This Topic

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Landslides in a changing climate

Gariano S. L., Guzzetti F.

Earth-Science Reviews (2016), [10.1016/j.earscirev.2016.08.011](https://doi.org/10.1016/j.earscirev.2016.08.011)

of the projected impact of climate change on landslide activity and abundance ... That climate changes affect the stability of natural and engineered slopes and have consequences on landslides

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Deciphering the effect of climate change on landslide activity: A review

Crozier M. J.

Geomorphology (2010), [10.1016/j.geomorph.2010.04.009](https://doi.org/10.1016/j.geomorph.2010.04.009)

Increased landslide activity is commonly listed as an expected impact of human-induced climate change ... climate change in affecting the temporal and spatial occurrence of landslides. © 2010 Elsevier B.V

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Physics of Slope Stability

Definition

Factor-of-safety is expressed as

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with shear strength s and shear stress τ on a potential surface of rupture.

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Interpretation:

- If $FOS > 1$, slope is stable.
- If $FOS = 1$, slope is at point of failure.
- If $FOS < 1$, slope will slide.

Physics of Slope Stability

Let

- c : cohesion
- γ : bulk density
- z : vertical depth
- β : slope angle
- u : porewater pressure
- ϕ : angle of internal friction

We expand the terms, such that the **resisting force** becomes

$$s = c + (\gamma z \cos^2 \beta - u) \tan \phi$$

and **driving force** becomes

$$\tau = \gamma z \sin \beta \cos \beta.$$

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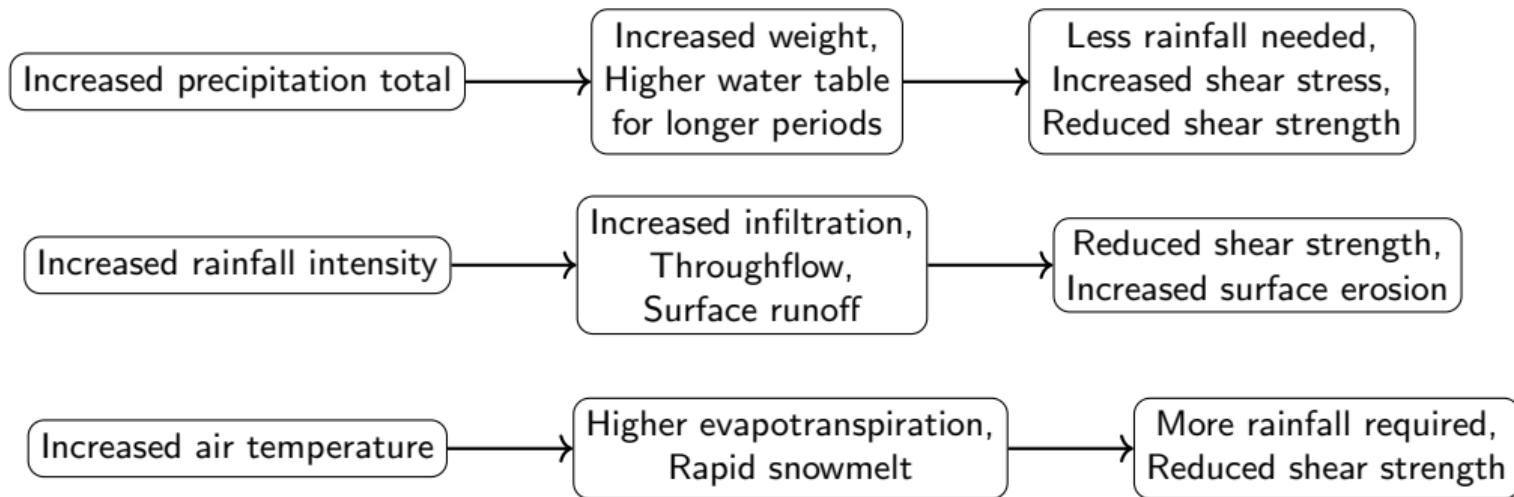
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How heavy rainfall strongly affect most factors:

- Increases water weight
- Increases porewater pressure
- Reduces soil suction
- Weathering cycles

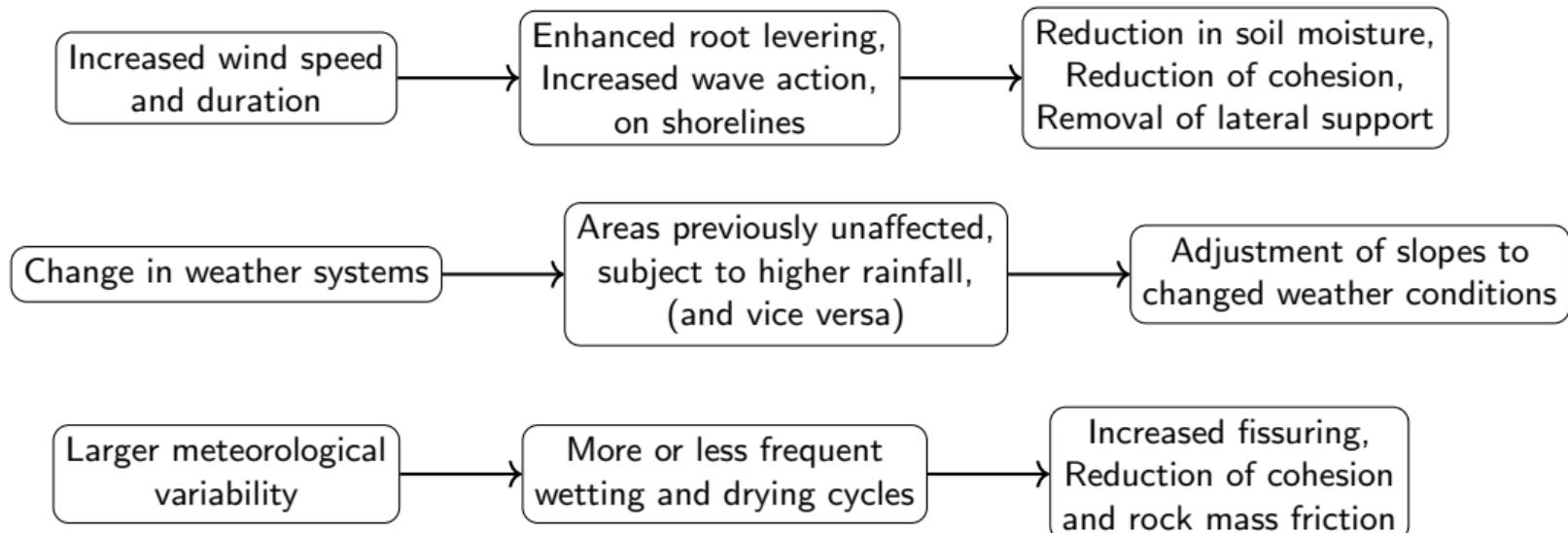
Physics of Slope Stability

Slope stability responses to climatic factors change



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Failure requires water to *accumulate* in the slope:

$$\text{Infiltration rate} > \text{Drainage rate}$$

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Soil *infiltration capacity* governs how much rainfall actually enters the slope.

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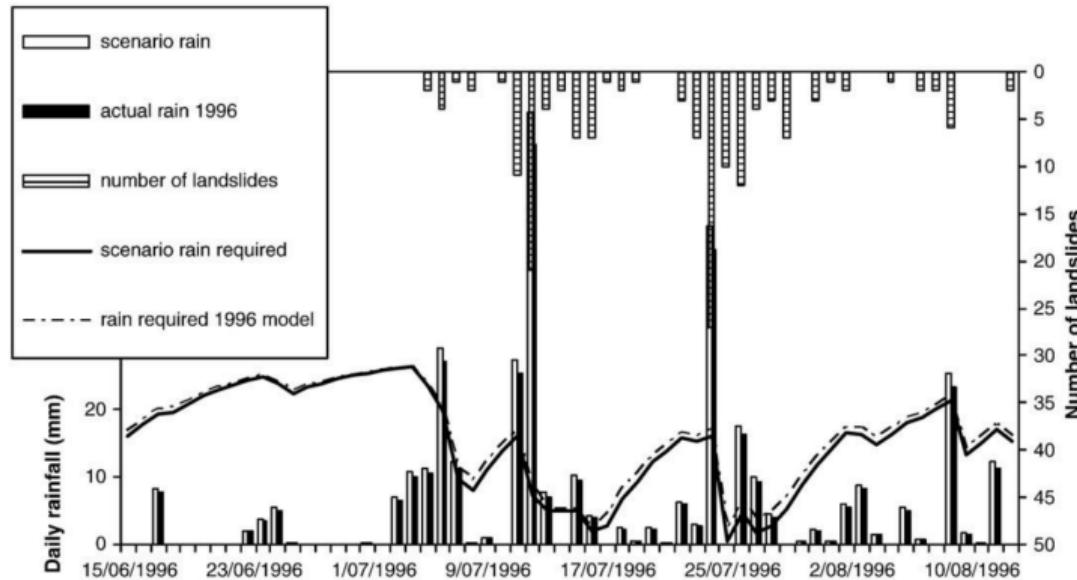
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Example in Hong Kong (So, 1971):

- ~702 landslides triggered by ~400 mm rainfall in one day.
- 35% occurred in forested areas, despite covering only 8% of the affected region.

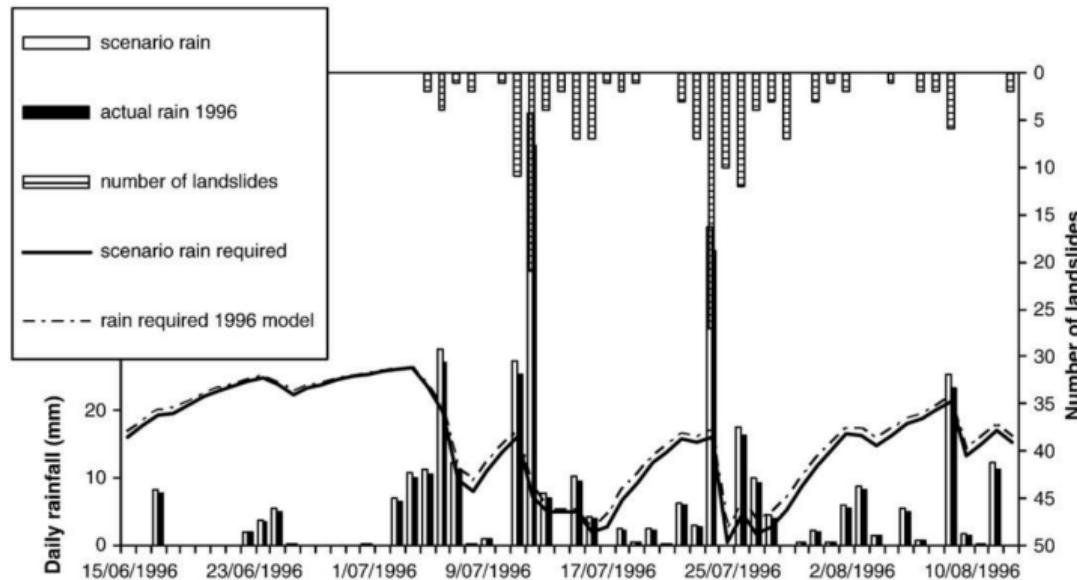
Climate-Landslide Model: Antecedent water status model



- The model empirically estimates the amount of event rainfall required to initiate landslides for the next 24 hour periods.

Author's model applied in Wellington City, New Zealand

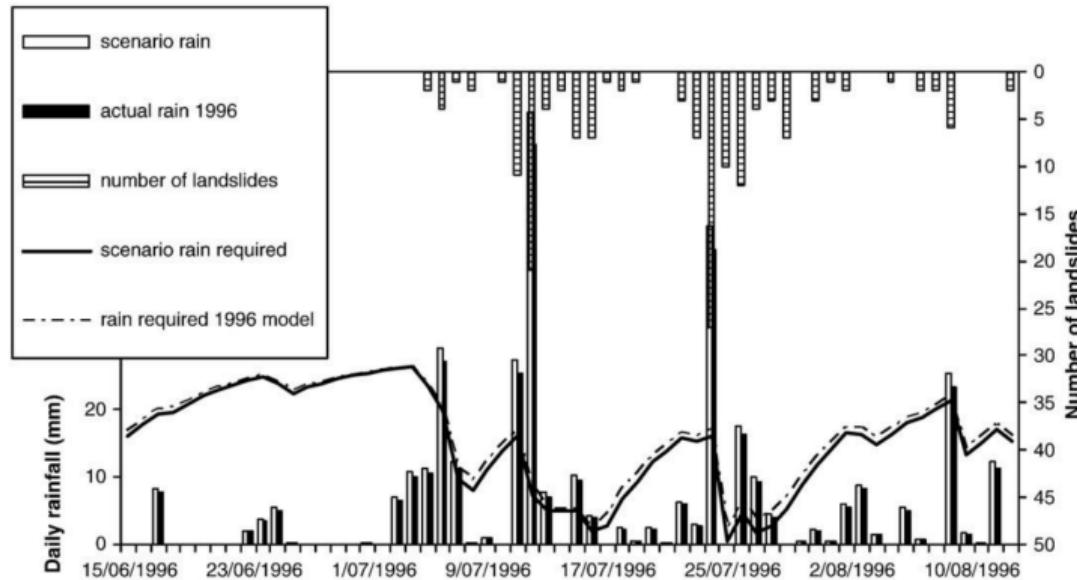
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- From IPCC downscaled prediction, we expect 8% increase of a 100-year daily rainfall in 2040.

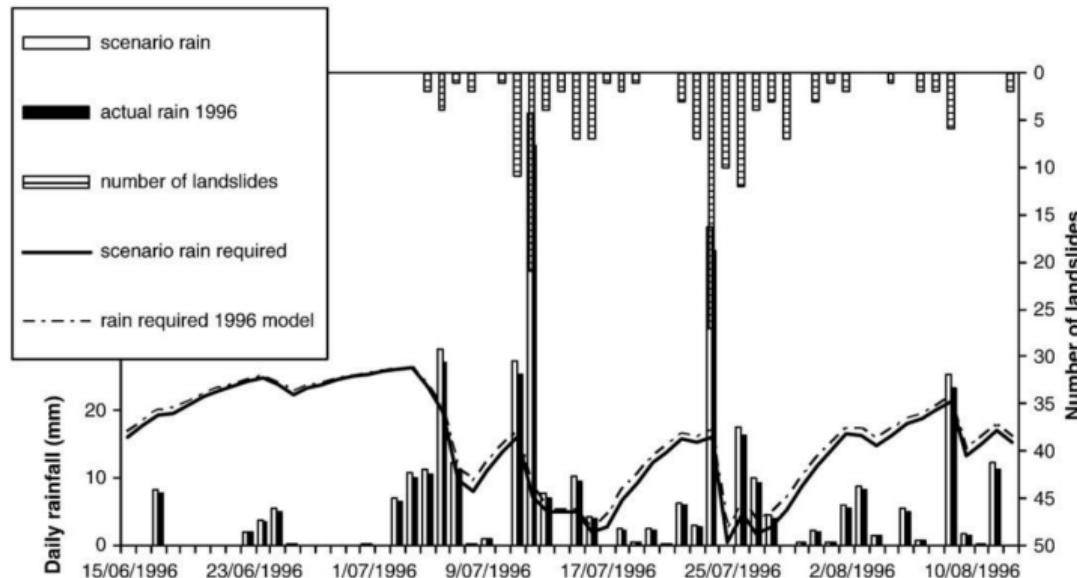
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Author's model applied in Wellington City, New Zealand

- With climate change scenario, two extra days of landslides could occur.
- Limitation: Downscaled rainfall data had too many uncertainties.

The Human Factor



Contrast in landslide distribution
between forested and pasture slopes in
Manawatu, New Zealand (Feb 2004)

- From empirical studies, human actions can hide or even outweigh the effects of climate change.

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 - Conversion from forest to pasture increases landslide probability by 3x.

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- The impact of human activity can be seen with greater certainty and magnitude.
- Examples from New Zealand:
 - Conversion from forest to pasture increases landslide probability by 3x.
 - Complete deforestation will increase runoff by 28%, whereas climate-driven runoff increase is 15% by 2080.

Take-Home Messages

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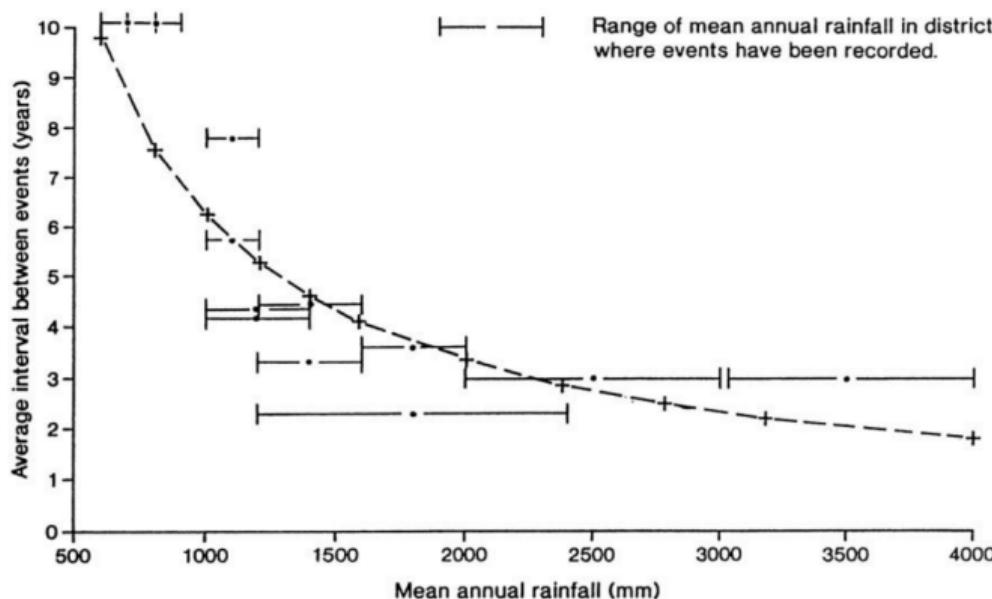
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- ② However, prediction is extremely uncertain.
- ③ Human land-use changes often dominate.
- ④ We need collaboration between climate and landslide modellers.

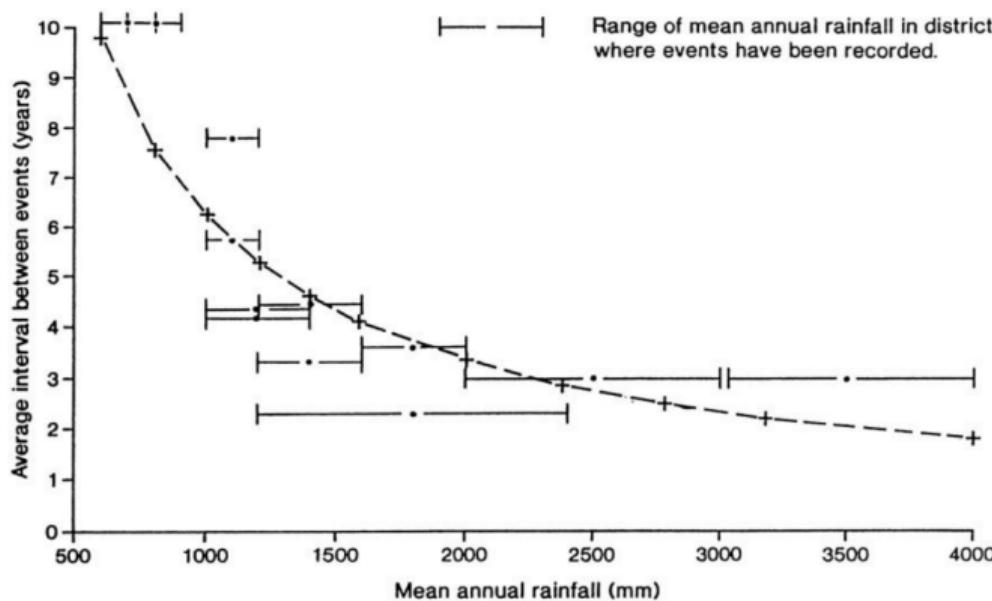
Climate-Landslide Model: Frequency vs increased rainfall



The frequency of landslide events (y) vs mean annual rainfall (x) around New Zealand (Hicks, 1995)

- Collected from 12 different catchments in New Zealand.
- The standard error of the estimate y is 1 year.
- An 8% rise in an area with annual rainfall of 1000 mm → number of events from 16 to 20 over a 100 year period.

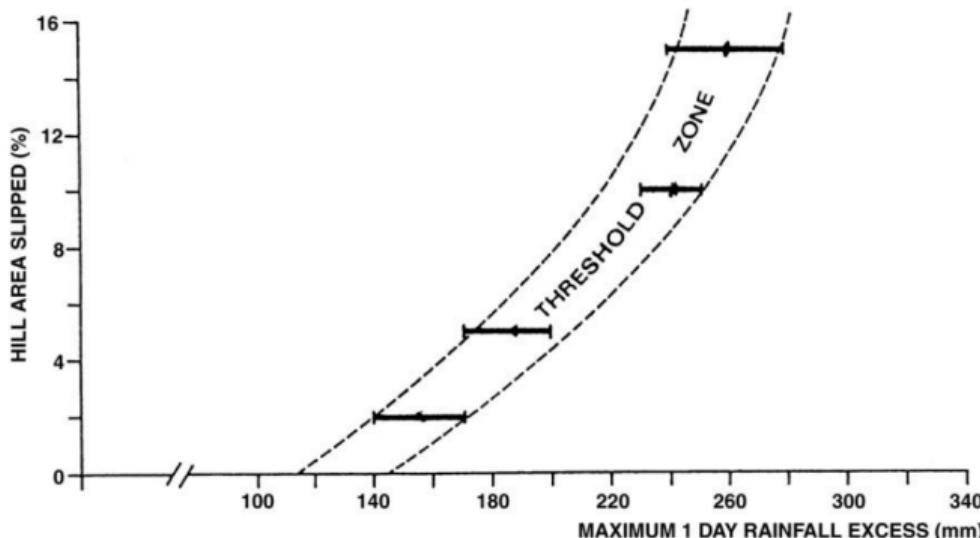
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- Uncertainty factors:
 - Predicted low and high estimates of mean precipitation is too large.
 - The standard error is still large.
 - Could not capture the full range of terrain, material, and vegetation throughout the country.

Climate-Landslide Model: Event Magnitude vs Storm Rainfall



Magnitude of landsliding and storm rainfall in
Wairoa, NZ (Eyles and Eyles, 1982)

- Can only be used with confidence in the locality where they are derived
- Still questionable still repeated landslide events may lead to 'event resistance' (increased threshold rainfall required)