

Atmospheric pressure compared to rainfall as landslide triggering factors along a hillslope

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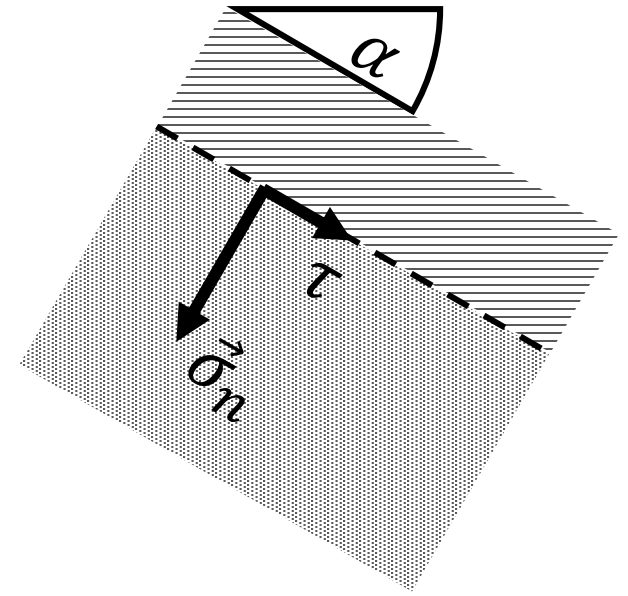
Slope stability model

The slope stability is evaluated through the Mohr-Coulomb criterion:

$$\tau_c = c + \sigma_{n \text{ eff}} \cdot \tan \varphi$$

$$\text{Safety factor: } F = \frac{c + \sigma_{n \text{ eff}} \cdot \tan \varphi}{\tau}$$

Any change of pore pressure will impact the effective normal stress $\sigma_{n \text{ eff}}$ and the overall stability



Triggering factors of landslides

Pore pressure from rainfall infiltration: 1D model

Landslide triggering by rain infiltration

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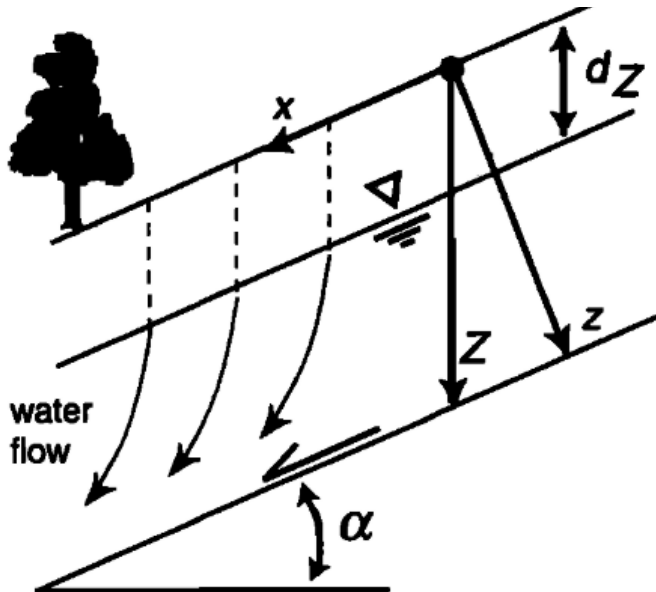


Figure from: Iverson, R. M. (2000).

Vertical infiltration as a diffusion process:

$$\frac{\partial \psi_{rain}}{\partial t} = D. \cos^2 \alpha. \frac{\partial^2 \psi_{rain}}{\partial z^2}$$

Solution as an impulse response function:

$$IR_{rain}(z, t = 0) = \sqrt{\left(\frac{\widehat{D}.t}{\pi}\right)}.e^{-\frac{z^2}{\widehat{D}.t}} - z.erfc\left(\sqrt{\frac{z^2}{\widehat{D}.t}}\right)$$

$$IR_{rain}(z, t > 0) = IR(z, t = 0) - \sqrt{\left(\frac{\widehat{D} \cdot (t - dt)}{\pi}\right)} \cdot e^{-\frac{z^2}{\widehat{D} \cdot (t - dt)}} - z \cdot \text{erfc}\left(\sqrt{\frac{z^2}{\widehat{D} \cdot (t - dt)}}\right)$$

Triggering factors of landslides

Pore pressure from atmospheric pressure changes: 1D model



Landslide movement in southwest Colorado triggered by atmospheric tides

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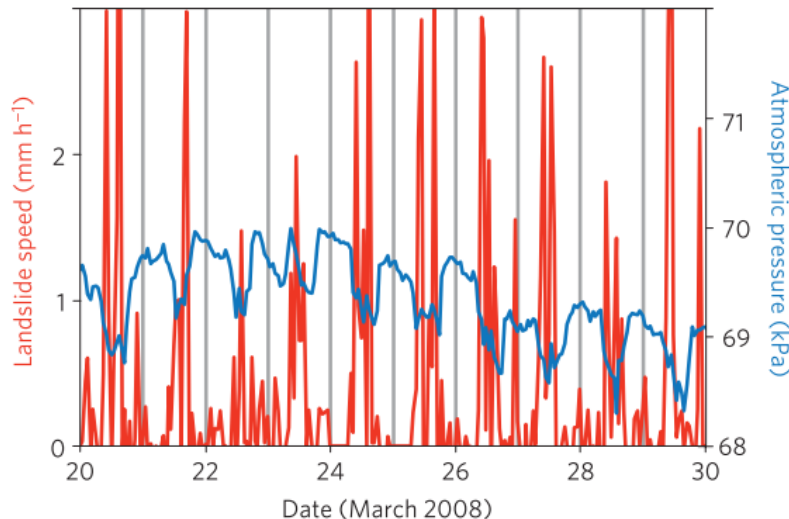


Figure from: Schulz, W. H., Kean, J. W., & Wang, G. (2009).

A similar diffusion process, a similar solution

$$\frac{\partial \psi_{atmo}}{\partial t} = D \cdot \frac{\partial^2 \psi_{atmo}}{\partial z^2}$$

Solution as an impulse response function:

$$IR_{atmo}(z, t = 0) = \text{erfc} \left(\sqrt{\frac{z^2}{D \cdot t}} \right)$$

$$IR_{rain}(z, t > 0) = IR(z, t = 0) - \text{erfc} \left(\sqrt{\frac{z^2}{D \cdot (t - dt)}} \right)$$

2D modelling

Hydrological model for water table variations:

- Dupuits Forchheimer assumption
- small variations compared to the aquifer thickness

$$T \frac{\partial^2 h}{\partial x^2} = S \frac{\partial h}{\partial t} - R$$

The response of aquifers to periodic forcing

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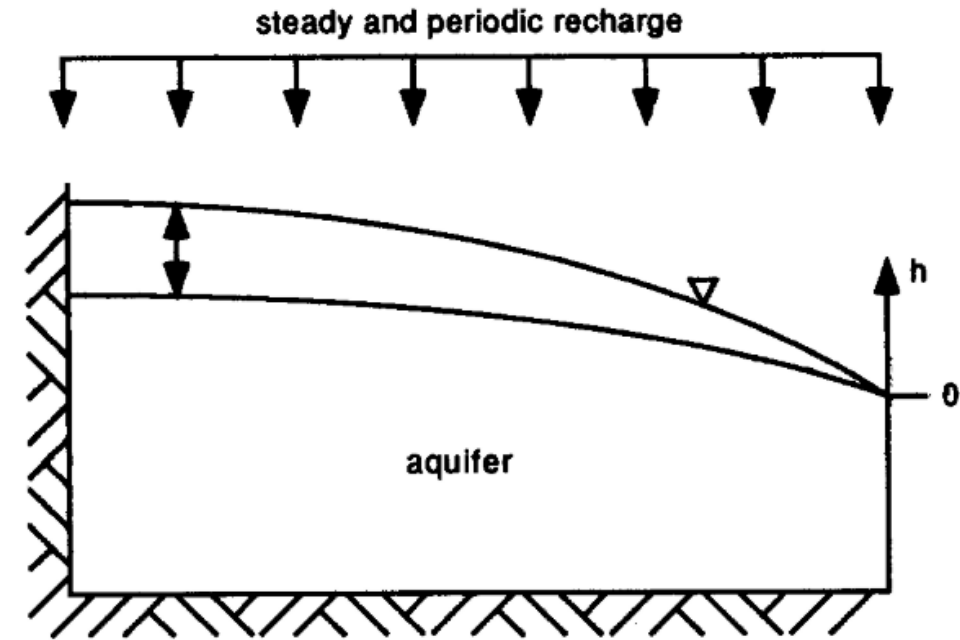
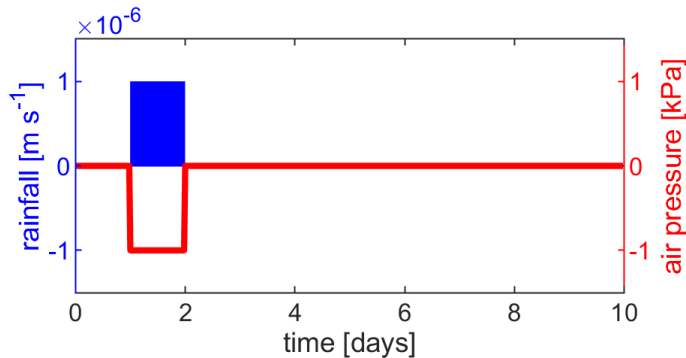


Figure from: Townley, L. R. (1995).

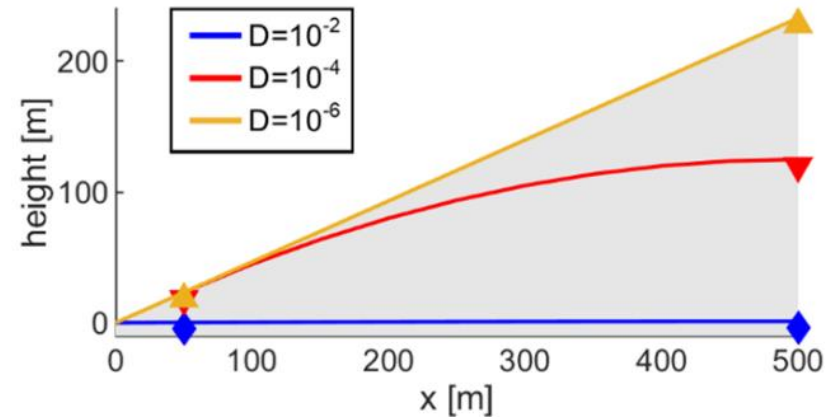
Synthetic tests

Response highly constrained by the diffusivity of the slope.

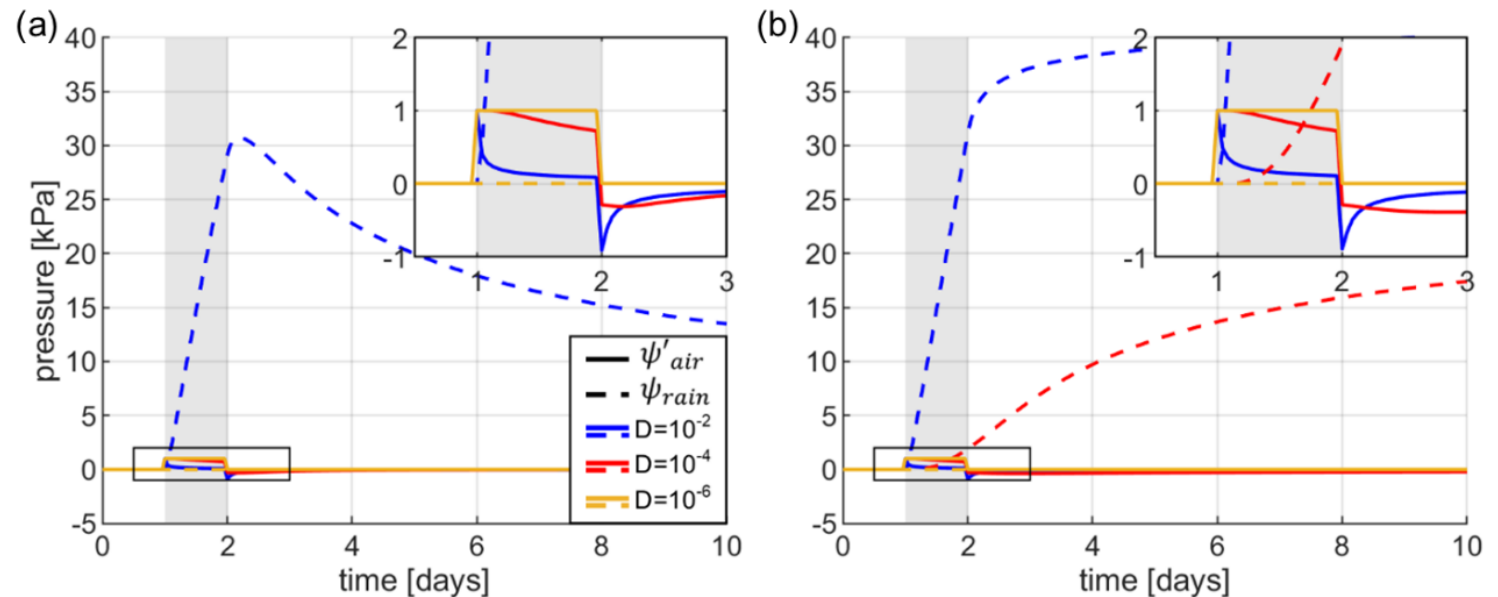
Downslope, at low diffusivities, the water table reaches the surface and can't induce pore pressure variations



Rainfall and atmospheric pressure inputs



Water table for different diffusivities (in $\text{m}^2 \cdot \text{s}^{-1}$). Markers represent points where the pore pressures are computed in the figure below: 5m under the water table (a) near the base of the hillslope at $x=50\text{m}$; and (b) at the top of the hillslope at $x=500\text{m}$.



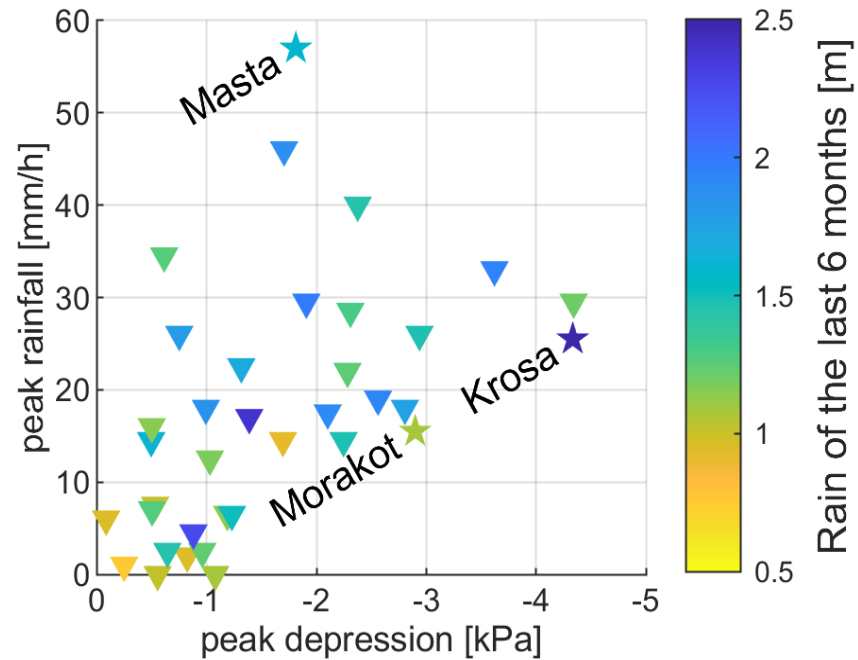
Rainfall induced pore pressure (dashed lines) and atmospheric induced pore pressure (solid line) computed at (a) $x=50\text{m}$ and (b) $x=500\text{m}$.

Real data

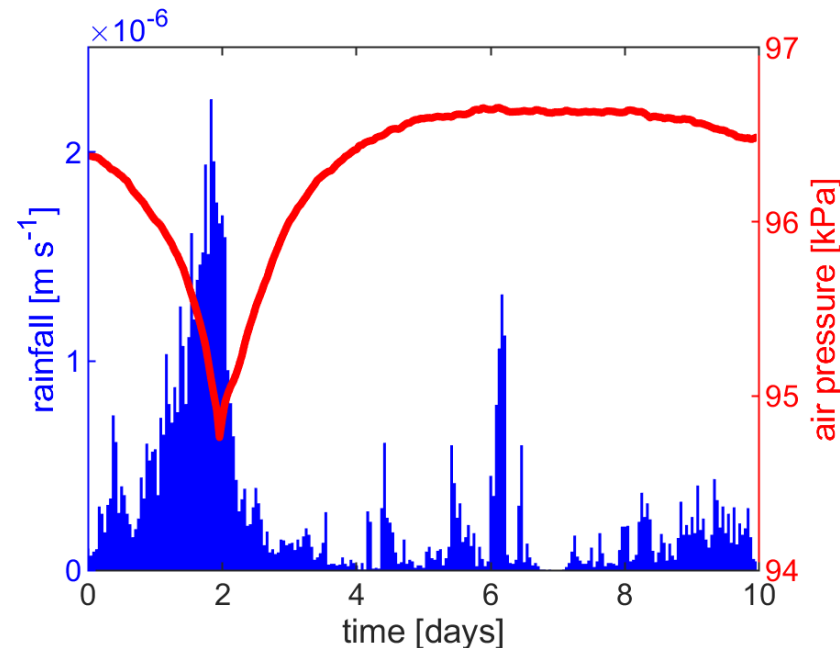
On real meteorological data:
rainfall and atmospheric
pressure over Taiwan from
2003 to 2017



Location of the weather station
(image from google maps)



Scatter of registered typhoons sorted by
maximum rainfall intensity, maximum
drop of atmospheric pressure, and and
function of the previous 6 months of
rainfall (colorscale)



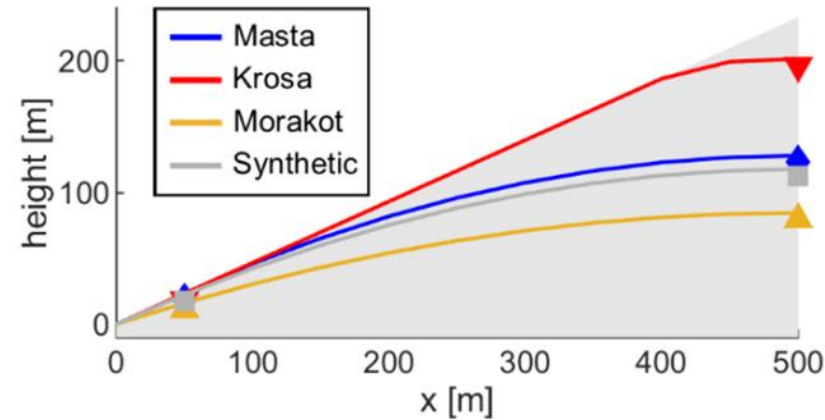
Rainfall intensity and atmospheric
pressure of the « synthetic typhoon ».
This event is created by taking the mean
of all typhoons events.

Typhoons

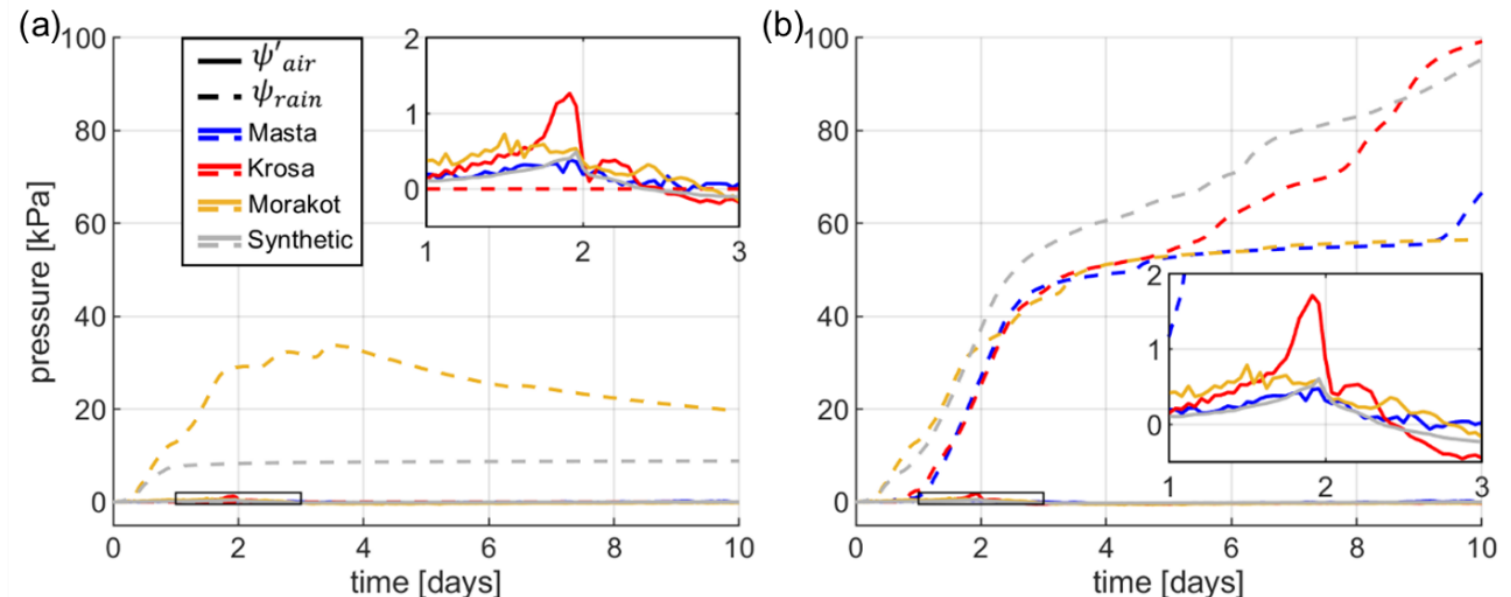
Even at a **high diffusivity** ($D=10^{-2}\text{m}^2.\text{s}^{-1}$), some typhoons strike a hillslope partially saturated by the previous 6 months.

Atmospheric effects are dominant for some events at the base of the slope.

Any lower diffusivity would nullify the rainfall response, and only leave the atmospheric effect for destabilising the slope.



Water table for different diffusivities typhoons at a **high diffusivity** ($10^{-2}\text{m}^2.\text{s}^{-1}$). Markers represent points where the pore pressures are computed in the figure below: 5m under the water table (a) near the base of the hillslope at $x=50\text{m}$; and (b) at the top of the hillslope at $x=500\text{m}$.



Rainfall induced pore pressure (dashed lines) and atmospheric induced pore pressure (solid line) computed at (a) $x=50\text{m}$ and (b) $x=500\text{m}$.

Conclusion

In Taiwan there are mainly clayey and silty soils, generally associated with low diffusivities, and some observations (Meunier et al., 2008) show a concentration of Typhoon-induced landslides towards the base of the slope.

This would emphasize on the effect of the atmospheric pressure on the slope stability.

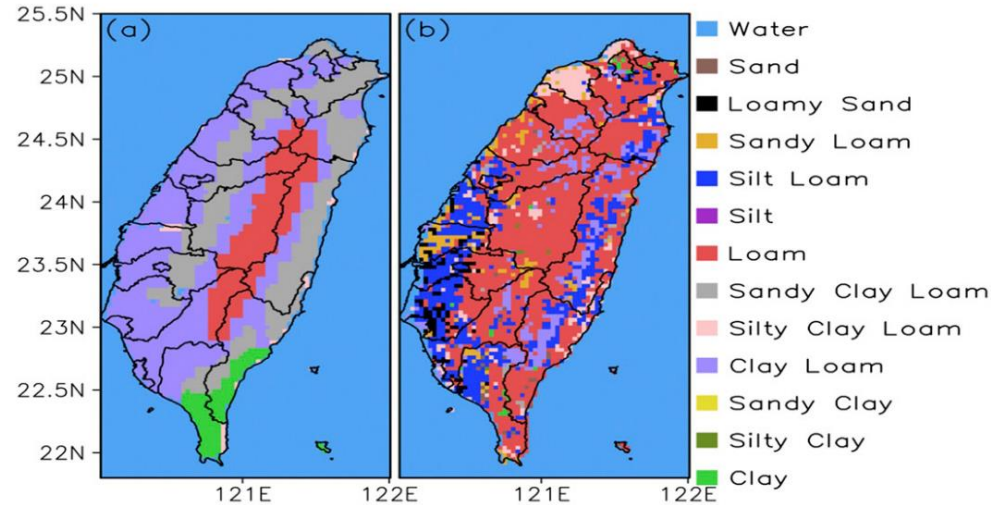


Figure from: Lin, T. S., & Cheng, F. Y. (2016).
Map of soil types in Taiwan

Figure from: Meunier, P., Hovius, N., & Haines, J. A. (2008).
Landslides repartition along the normalized hillslope in Taiwan

