GIS-FSLAM-FORM: A QGIS plugin for fast probabilistic susceptibility assessment of rainfall-induced landslides at regional scale

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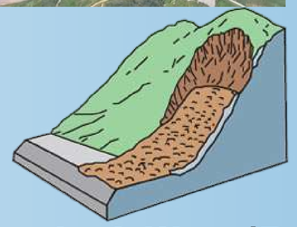
Research Motivation & Study Goals

Research motivation:

- Landslide susceptibility assessment
- Fast Shallow Landslide Assessment Model (FSLAM)
- First order reliability mehod (FORM-HLRF_x)

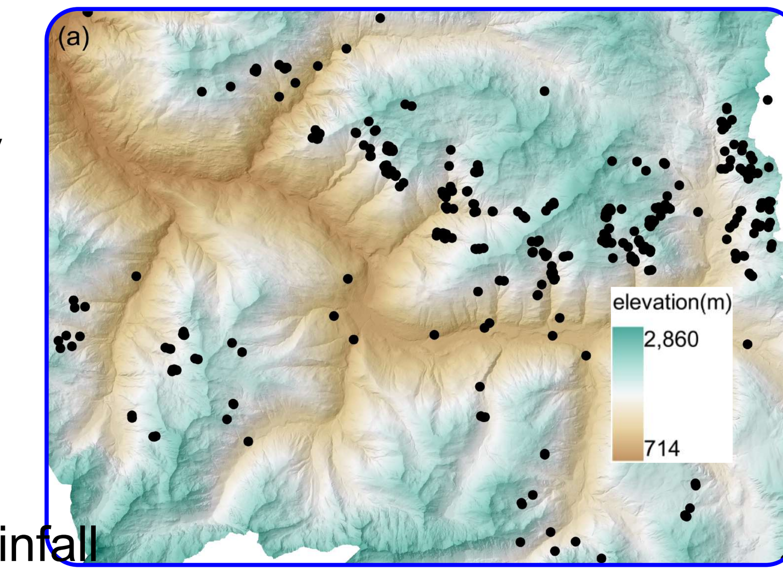
Study goals:

- **GIS-FLSAM-FORM plugin developed**
- **Parameter uncertainties in regional scale**
- **Factor of safety(FoS), Reliability index(RI), Failure probability (Pf)**



Study area & Datasets

- **Soil properties:** soil cohesion, friction angle, density, hydraulic conductivity and soil thickness
- **LULC**: the root cohesion (Cr)
- **CN**: curve number
- **Rainfall information**: antecedent rainfall & event rainfall

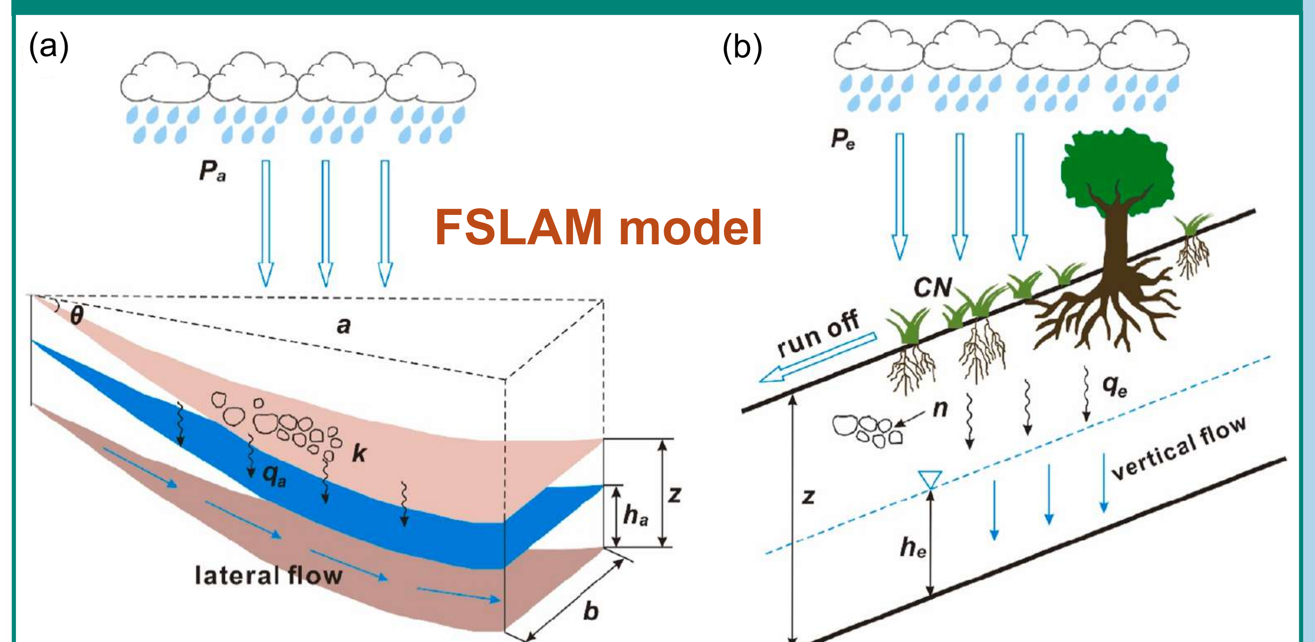


The Val d'Aran study area.
(a) Location of the study area in the Pyrenees (red dot).
(b) Digital elevation model (DEM) with shaded relief and the landslides triggered by the 2013 episode

Lithological class	C_s-min/max (kPa)	φ-min/max (°)	h (m)	K (m/s)	n (-)	ρ (kg/m³)	HSG (-)
Alluvial	0/3	35/45	4	1×10^{-3}	0.3	2000	A
Colluvium	1/3	25/35	1.5	1×10^{-6}	0.3	2000	B
Scree	0/3	40/50	3	1×10^{-2}	0.4	2000	A
Till	0/5	30/40	2	1×10^{-5}	0.3	2000	B
Conglomerate*	0/5	35/45	3	1×10^{-5}	0.35	2000	A
Sandstone*	1/5	35/45	3	1×10^{-4}	0.35	2000	A
Mudstone*	1/5	20/30	2	1×10^{-6}	0.3	2000	B
Granitic rock + quartzite*	0/4	35/45	2	1×10^{-5}	0.3	2000	A
Hornfels-marble*	1/3	30/40	2	1×10^{-5}	0.3	2000	A
Limestone*	1/3	20/35	1.5	1×10^{-6}	0.3	2000	B
Phyllite-slate*	0/5	20/35	2	1×10^{-6}	0.3	2000	B

LULC	C_r-min/max (kPa)	CN-A (-)	CN-B (-)	CN-C (-)	CN-D (-)
Forest	4/14	40	60	69	76
Shrubs	3/6	43	65	76	82
Grassland	2/4	49	69	79	84
Bare soil	0/0	77	86	91	94
Scree	0/0	30	30	30	30
Weathered bedrock	0/0	77	86	91	94
Intact bedrock	0/0	77	86	91	94
Urban area	0/1	90	92	96	98
Water	999/999	100	100	100	100
Glacier-snow	999/999	100	100	100	100

Method



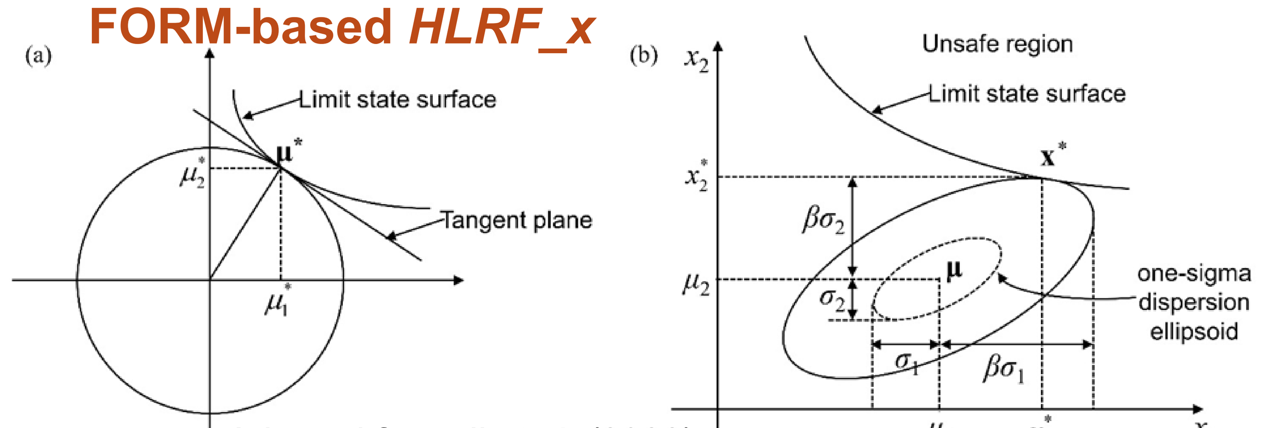
Adapted from Medina et al. (2021)

$$FS = \frac{C}{g\rho_s z\cos\theta\sin\theta} + \left(1 - \left(\left(\frac{a}{b}\right)\frac{q_a}{Kz\sin\theta\cos\theta} + \frac{q_e}{n\cdot z}\right)\left(\frac{\rho_w}{\rho_s}\right)\right)\left(\frac{\tan\varphi}{\tan\theta}\right)$$

$$FS = C_1 - q_a C_2 - q_e C_3$$

$$\begin{cases} C_1 = \dfrac{C}{g\rho_s z\cos\theta\sin\theta} + \dfrac{\tan\varphi}{\tan\theta} \\ C_2 = \left(\dfrac{a}{b}\right)\dfrac{1}{Kz\sin\theta\cos\theta}\left(\dfrac{\rho_w}{\rho_s}\right)\left(\dfrac{\tan\varphi}{\tan\theta}\right) \\ C_3 = \dfrac{1}{n\cdot z}\left(\dfrac{\rho_w}{\rho_s}\right)\left(\dfrac{\tan\varphi}{\tan\theta}\right) \end{cases}$$

FORM-based *HLRF_x*



Adapted from Ji et al. (2022)

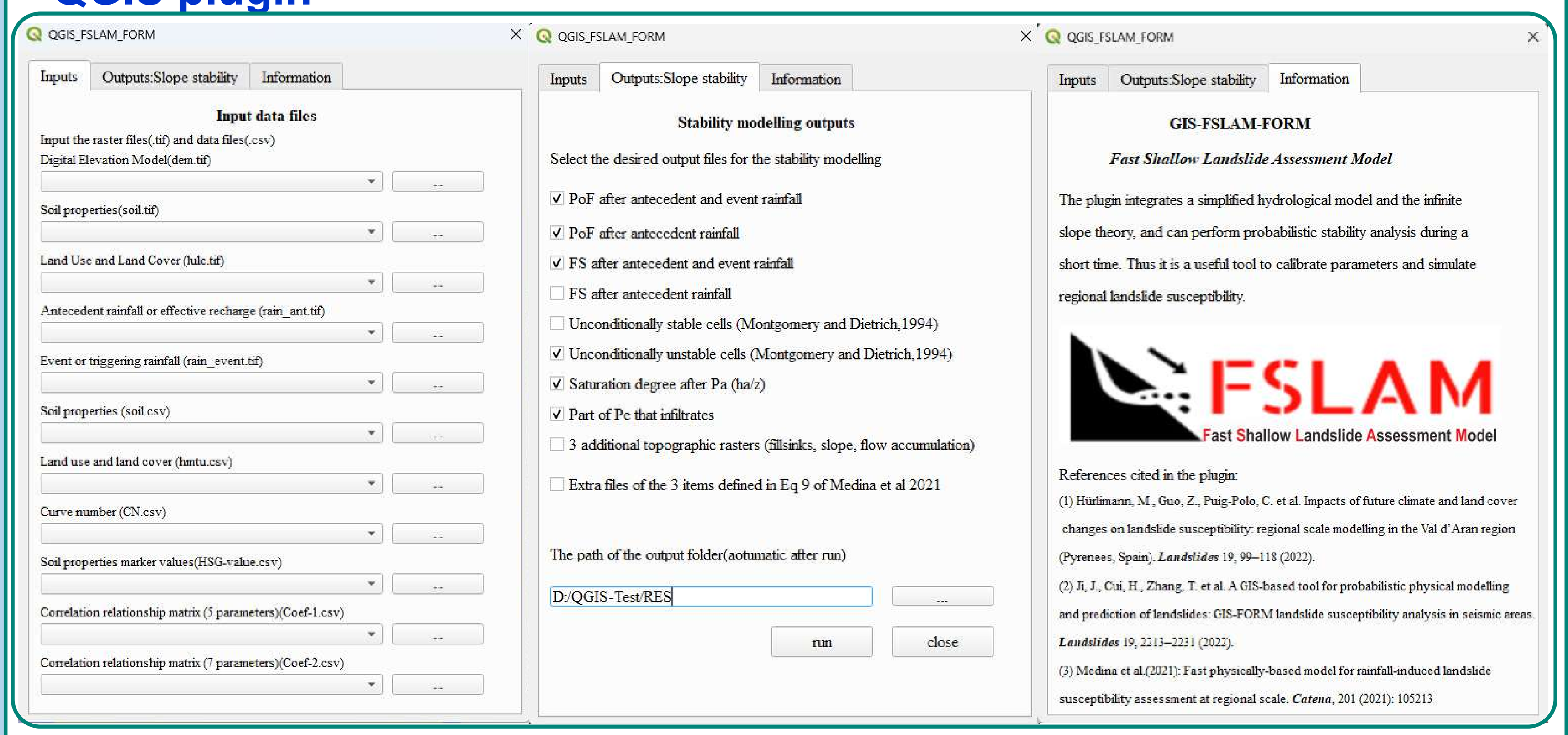
$$\mathbf{x}_{k+1} = \boldsymbol{\mu}_k^N + \frac{1}{\nabla g(\mathbf{x}_k)^T \mathbf{T}_k \nabla g(\mathbf{x}_k)}\left[\nabla g(\mathbf{x}_k)^T\left(\mathbf{x}_k - \boldsymbol{\mu}_k^N\right) - g(\mathbf{x}_k)\right]\mathbf{T}_k \nabla g(\mathbf{x}_k)$$

$$\beta = \sqrt{\boldsymbol{n}^{*T}\mathbf{R}^{-1}\boldsymbol{n}^*} = \sqrt{\left[\frac{x_i^* - u_i^N}{\sigma_i^N}\right]^T \mathbf{R}^{-1}\left[\frac{x_i^* - u_i^N}{\sigma_i^N}\right]}$$

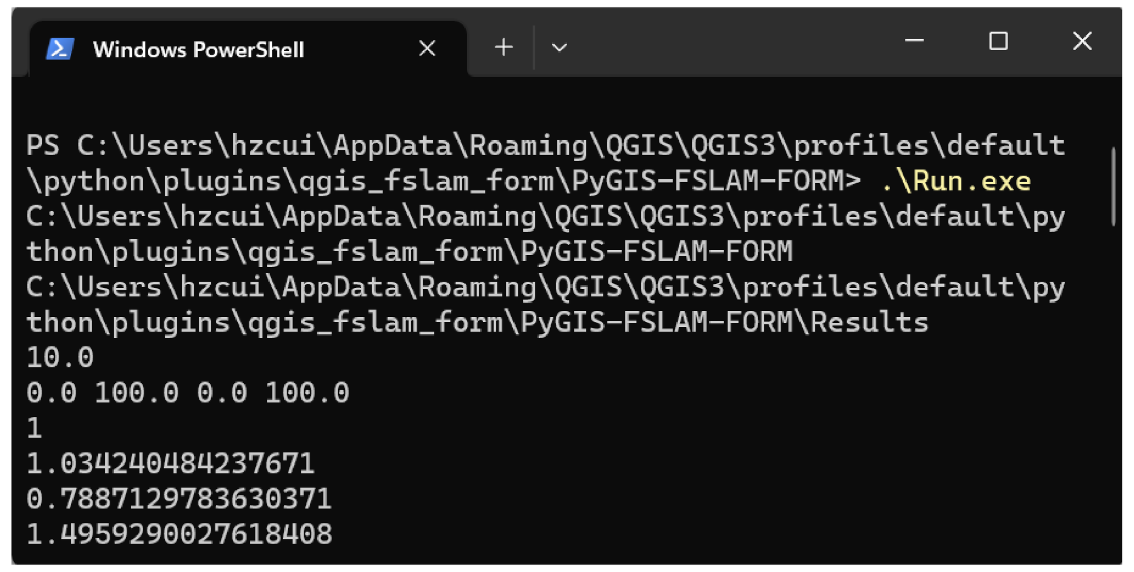
$$\boxed{P_f = \Phi(-\beta)}$$

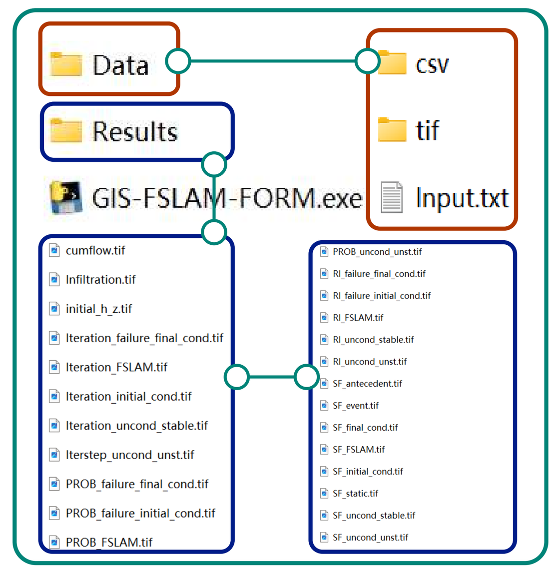
Results of software developed: GIS-FSLAM-FORM

- **QGIS plugin**



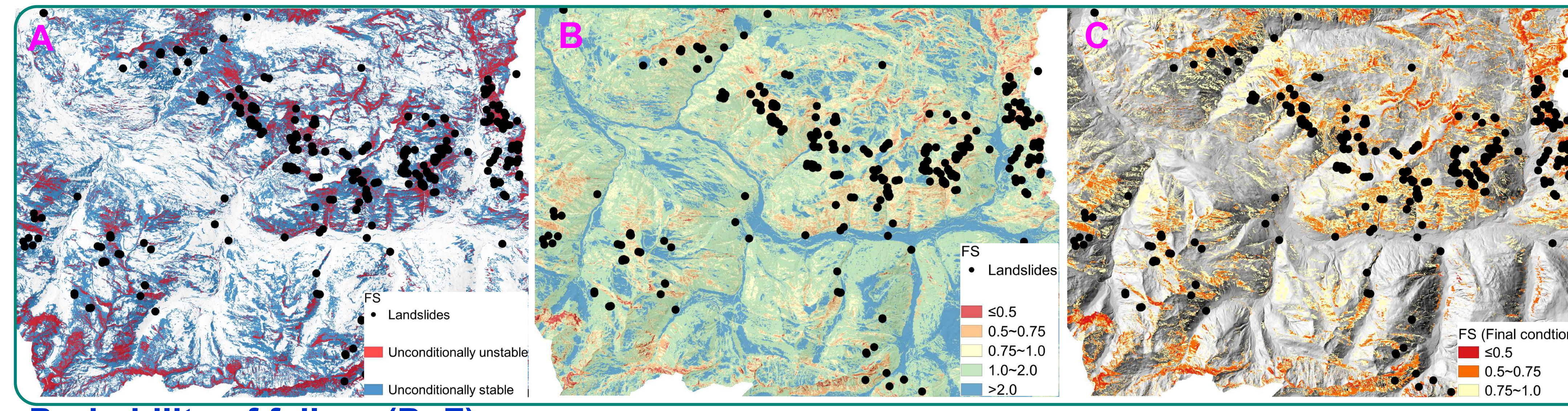
- **Windows software**





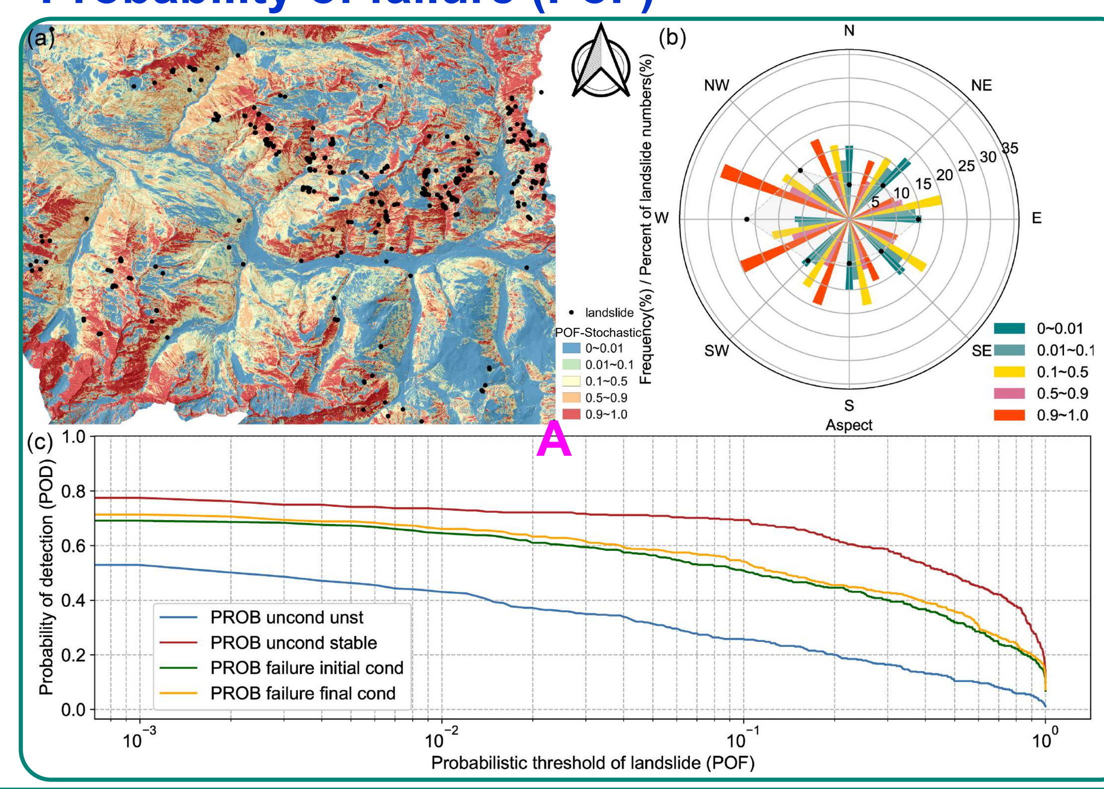
Simulations Results

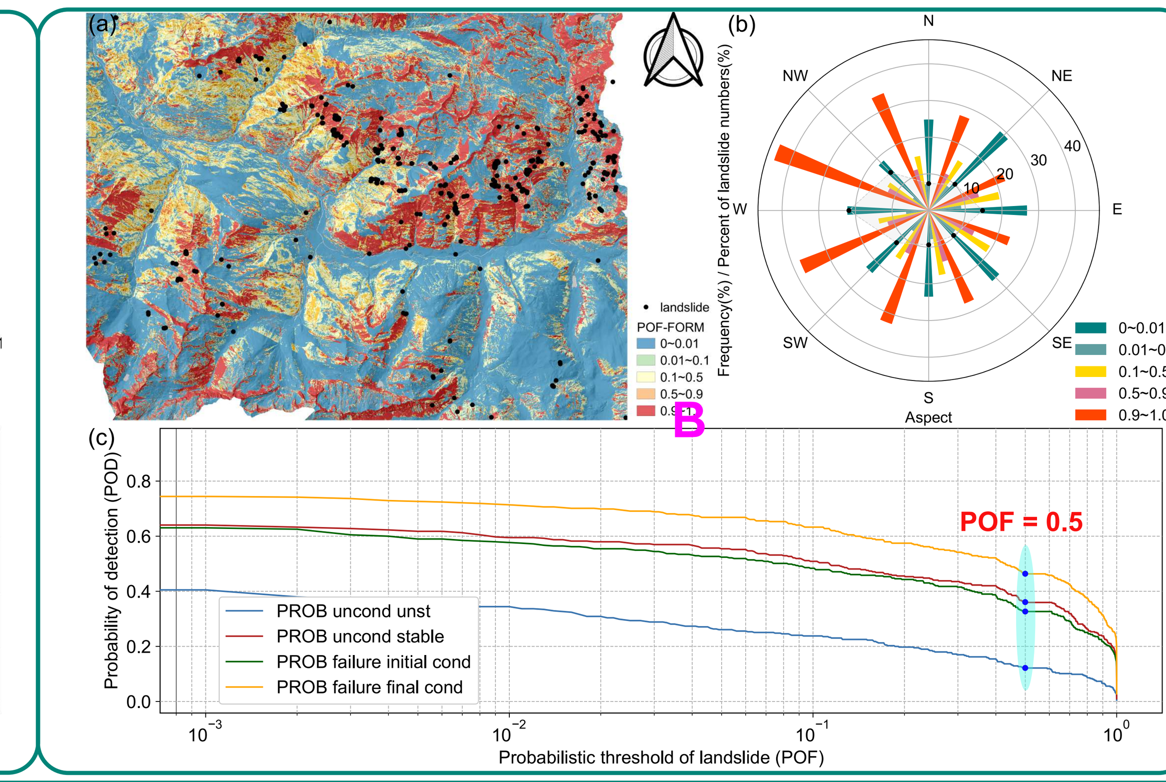
- **Factor of safety (FS)**



- **A:** The cells subject to unconditionally stable & unconditionally unstable
- **B:** FS after effective antecedent recharge
- **C:** FS after effective antecedent recharge and event rainfall

- **Probability of failure (PoF)**





- **A:** The calculated POF based on FSLAM-stochastic approach (normal-uncorrelation)
- **B:** The calculated POF based on FSLAM-FORM approach (lognormal-correlation)

References

- Medina, V., Hürlimann, M. et al. (2021). Fast physically-based model for rainfall-induced landslide susceptibility assessment at regional scale. ***Catena***, 201, 105213.
- Ji, J., Cui, H., Zhang, et al. (2022). A GIS-based tool for probabilistic physical modelling and prediction of landslides: GIS-FORM landslide susceptibility analysis in seismic areas. ***Landslides***, 19(9), 2213-2231.

Conclusions

- The plugin enables the calculation of regional landslide susceptibility by considering the influence of both **antecedentand and event rainfall conditions**.
- The **HLRF_x reliability method** based on the FORM has been firstly integrated into the FSLAM model.
- The results demonstrate that the noval framework successfully **overcomes** the limitation of the original model which was only able to consider two **uncorrelated parameters**, namely the **cohesion and the internal friction angle**.
- This enhancement has significantly improved the **generalizability** of the **FSLAM model**.

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