Advancing slope stability computations in distributed hydrologic applications

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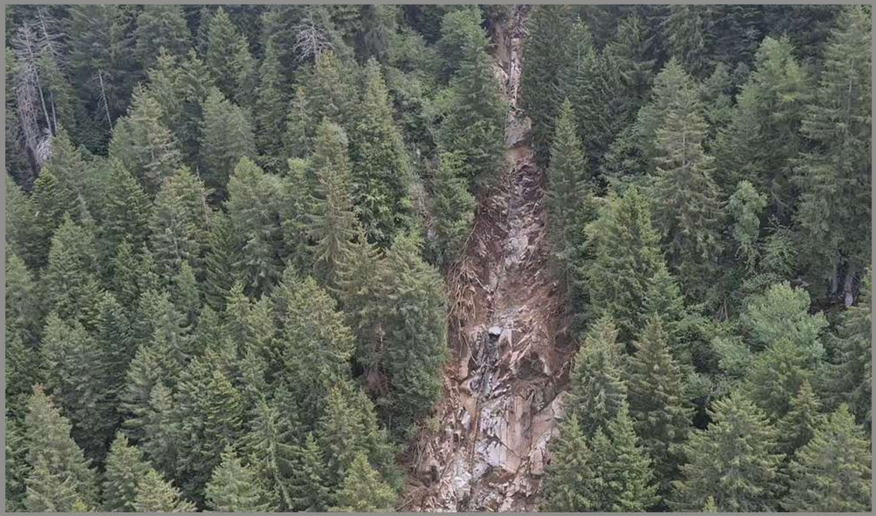
Introduction

Settlements in mountain areas can be endangered by the occurrence of debris flows, which are often fuelled by landslides or soil slips happening during an extreme rainfall event.

The pictures reported show an event occurred in Niardo, located in Northern Italy, where a cumulated rainfall of 180 mm was recorded in only 2 hours (maximum intensity 250 mm/h).



Slope instability at catchment scale

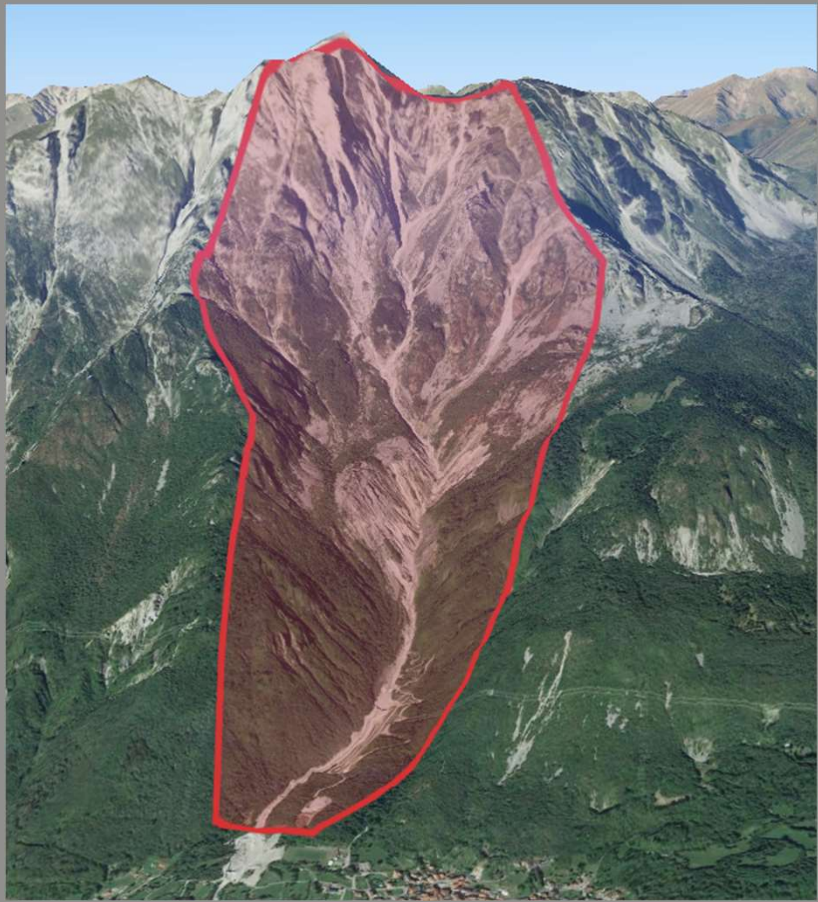
Precipitation history

Geotechnical parameters
- Soil depth map
- Soil friction parameters map
- Porosity map
- Hydraulic conductivity map

Digital Elevation Model (DEM)

Hydrological model
- Transient saturation
- Discharge

Slope stability model
- Factor of Safety (FS)
- Unstable areas



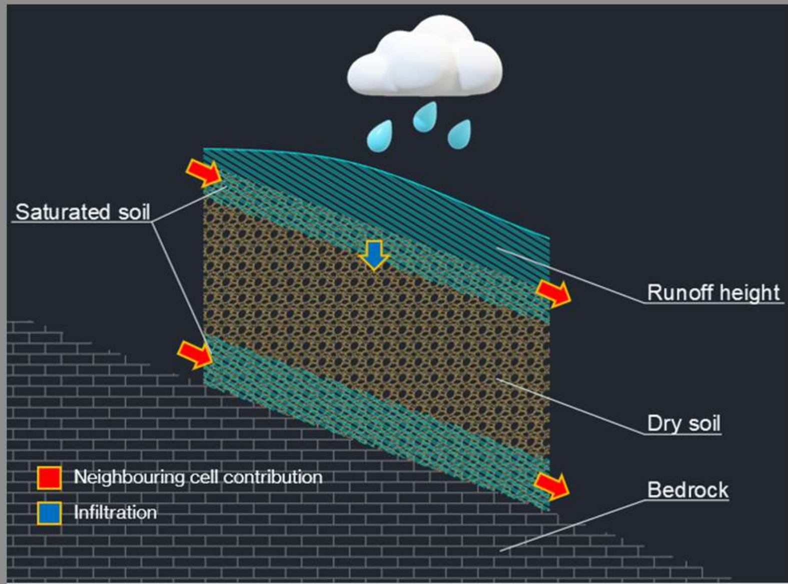
Hydrological model

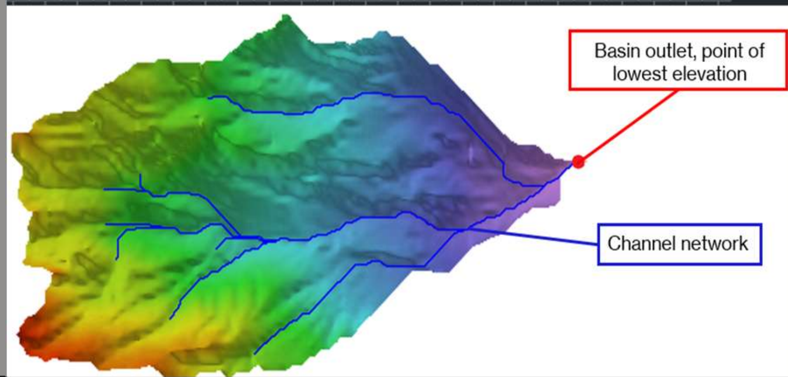
The hydrological model provides local and transient relative soil saturation at each location in the watershed, as well as the shallow subsurface flow and surface runoff.

The model computes a Space Filling Drainage Network (SFDN) and a channel network starting from the DEM of the catchment.

This enables a topological representation of the catchment where each cell is connected to its neighbour in the steepest direction.

Using suction, porosity, saturated permeability, soil depth and local Manning's coefficient, the hydrological model computes the transient relative soil saturation using the Green-Ampt method.





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Pilotti, M. and Rosso, R. (1990) "SHELL: a general framework for modelling the distributed response of a drainage basin", *Computational Methods in Surface Hydrology*.

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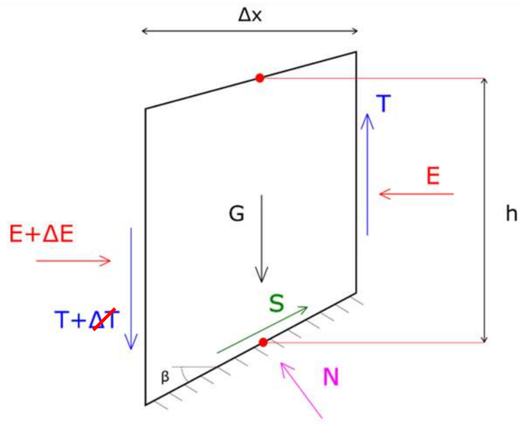
Slope stability model

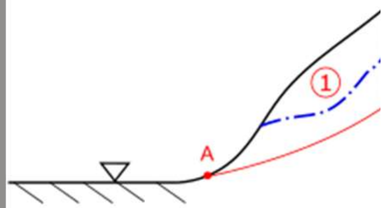
In order to improve the methodology currently used in this applications, we propose a variation on the well known simplified Janbu method.

In this procedure we consider the slope progressively, starting from the toe, compute the FS, then adding another slice, we recompute another FS and so on, up to the crest.

The last FS computed in this procedure corresponds to the FS of the whole slope, computed using the classical simplified Janbu method.



$$\Delta T \approx 0$$



$$FS = \frac{\sum_{i=1}^{n}\{c'\,a_i + [N(FS) - u_i a_i]\tan\phi'\}\cos\beta_i}{E_B - E_A + \sum_{i=1}^{n} N_i(FS)\sin\beta_i}$$

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Janbu, N. (1973) "Slope stability computations" *Embankment Dam Engineering*

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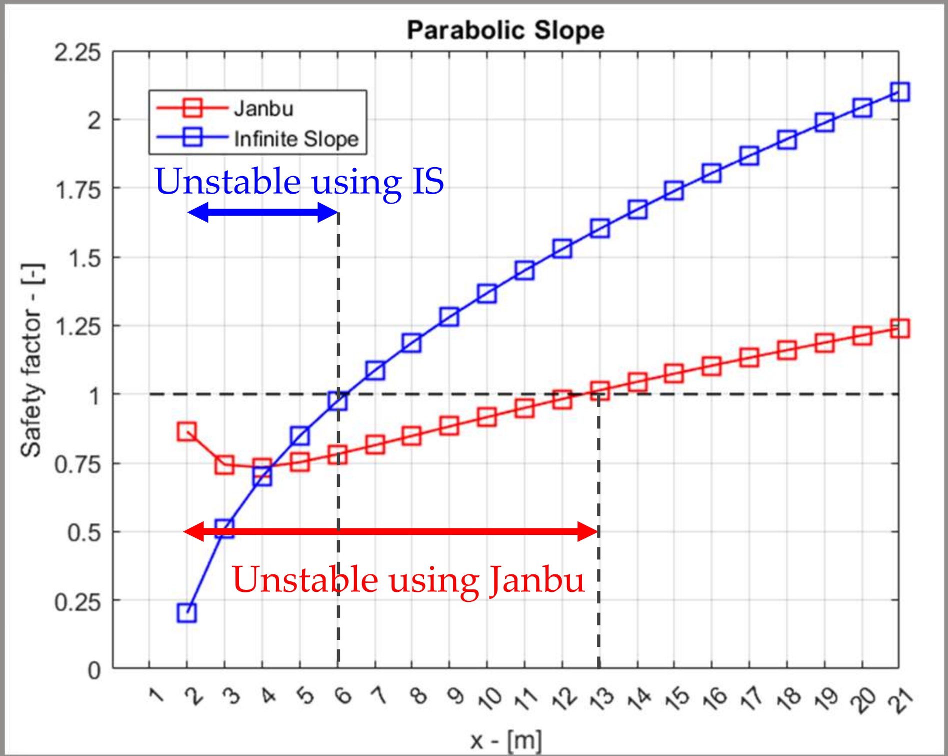
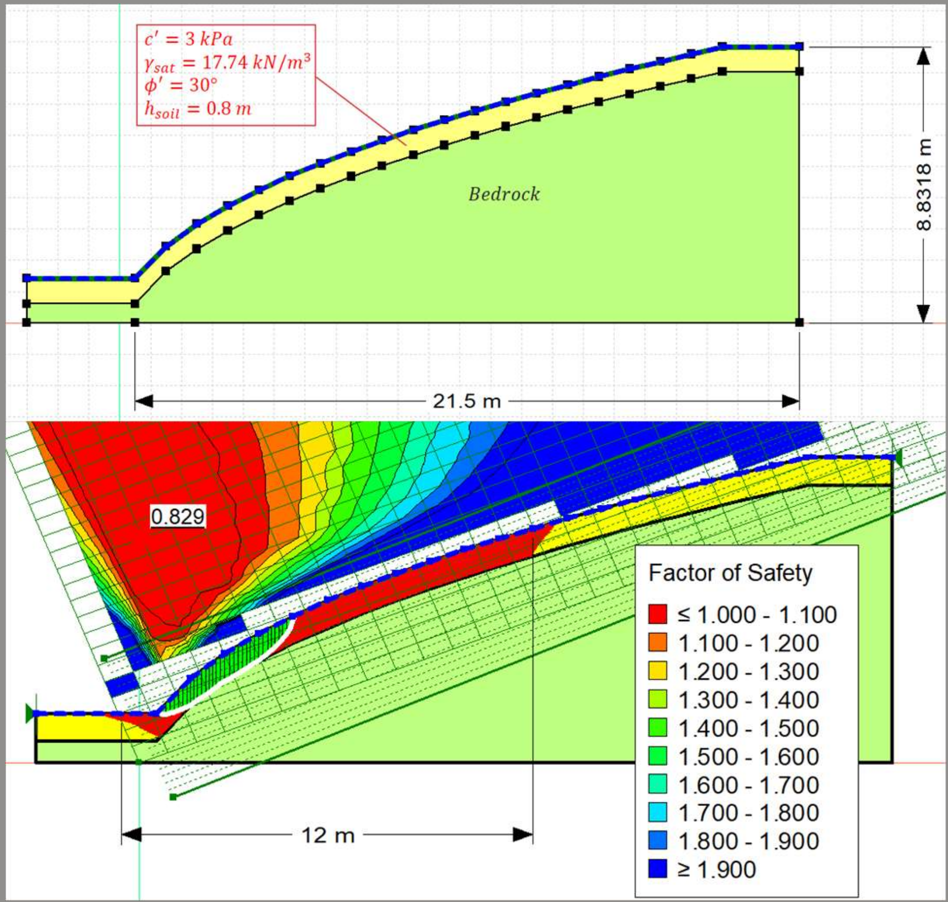
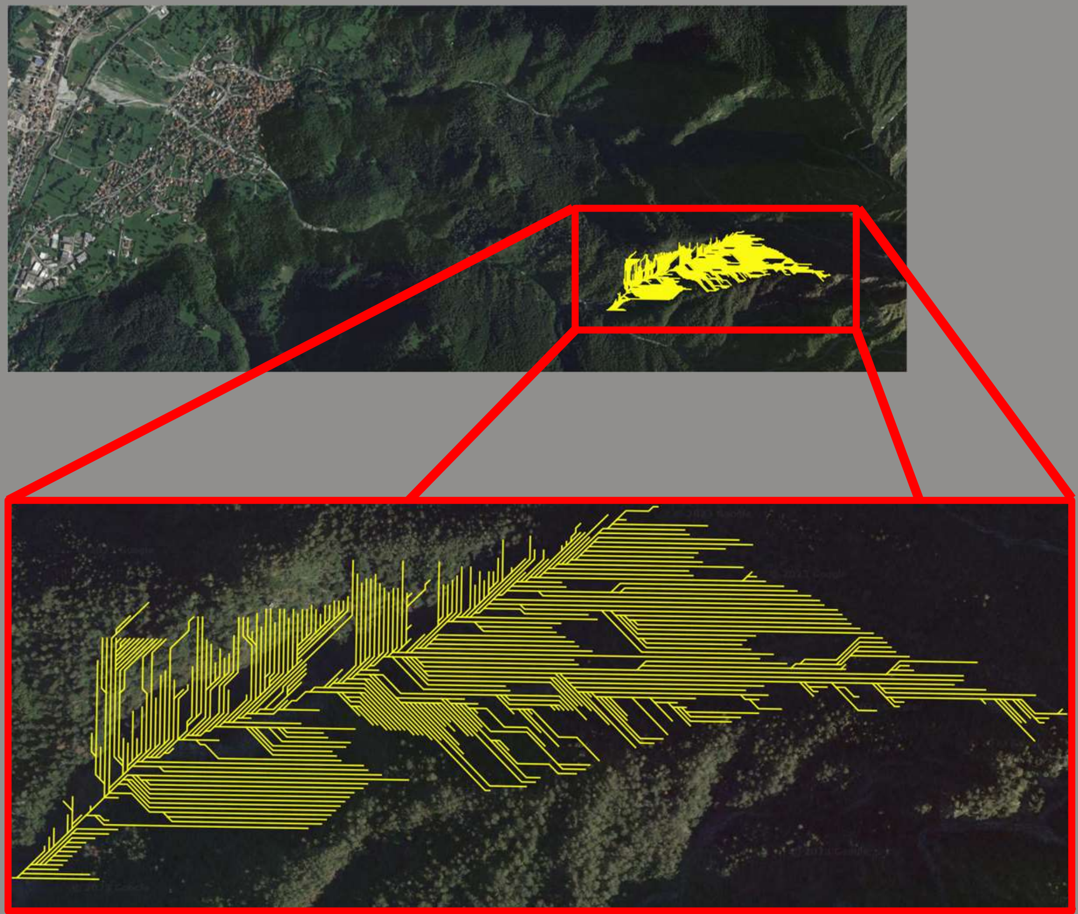
Slope stability model validation

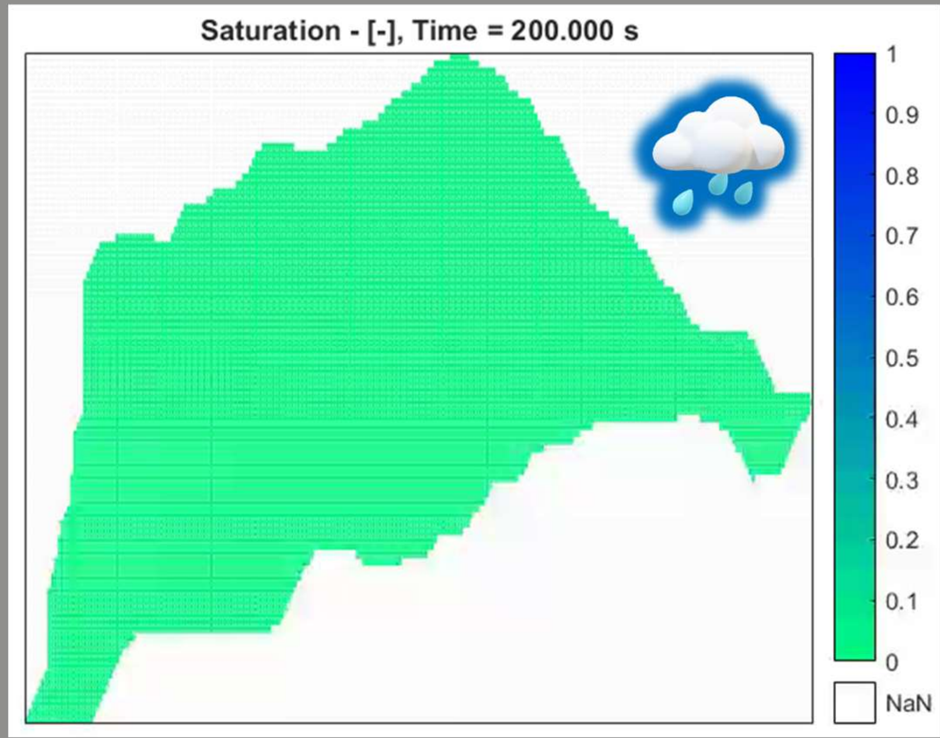
Comparison between the progressive Janbu method, Infinite Slope (IS) and Slope/W (GeoStudio) for a simple parabolic slope.





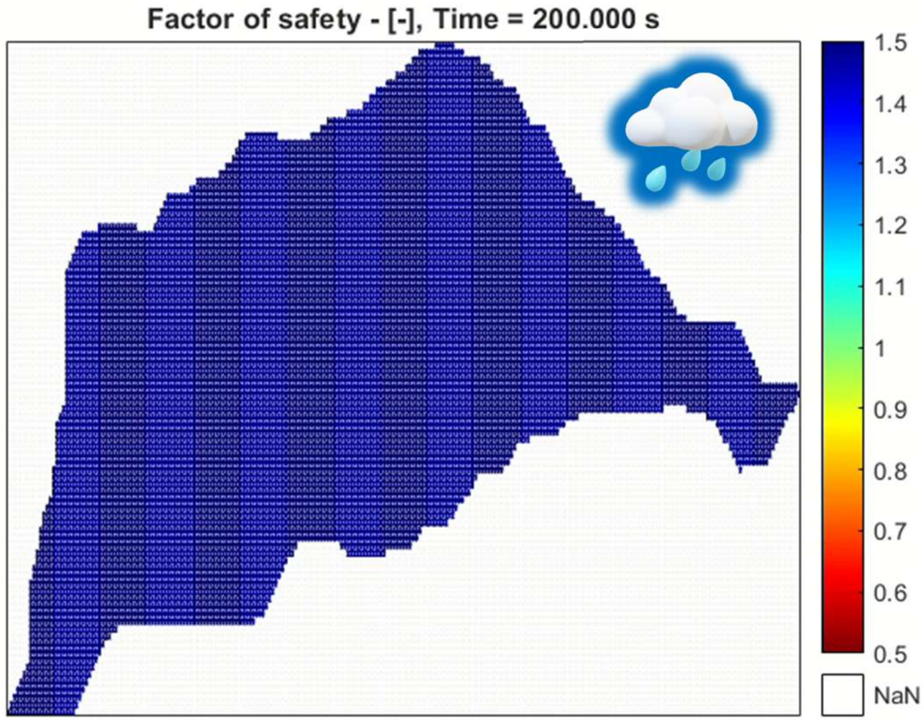
Catchment scale application



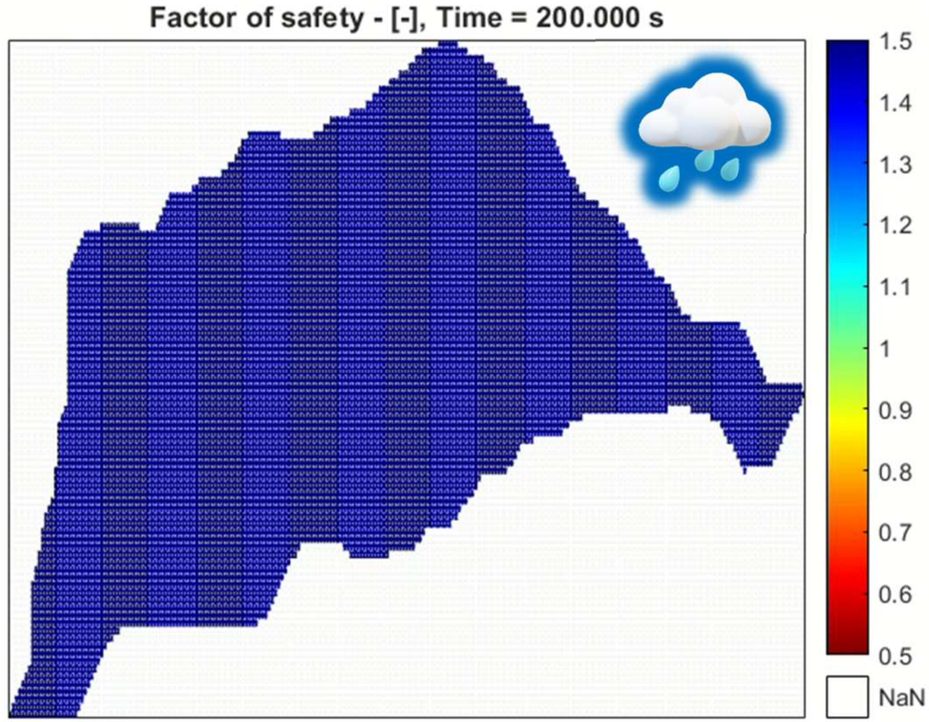


Catchment near the town of Niardo, 1 km^2 subjected to a constant rainfall event of 100 mm/h.

Infinite Slope vs Janbu Progressive

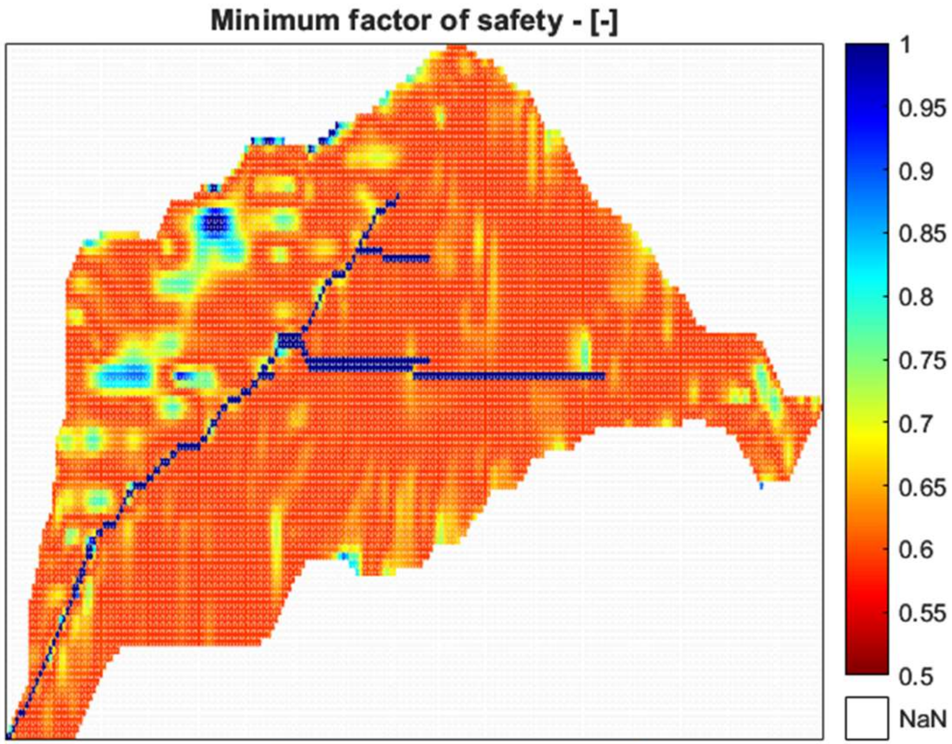


Infinite Slope

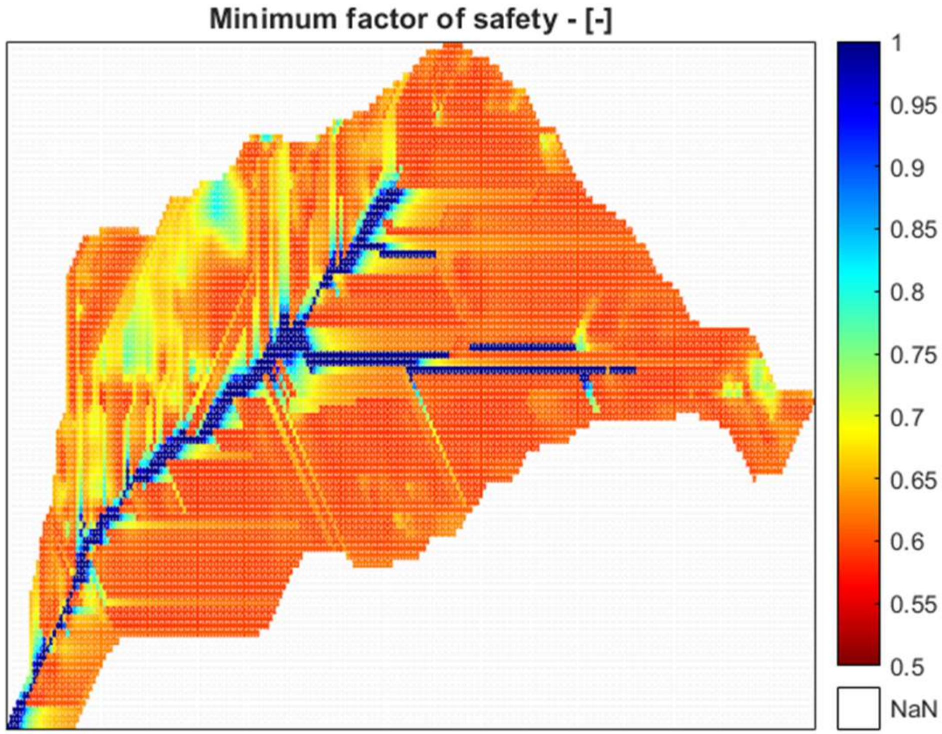


Janbu Progressive

Infinite Slope vs Janbu Progressive



Infinite Slope



Janbu Progressive

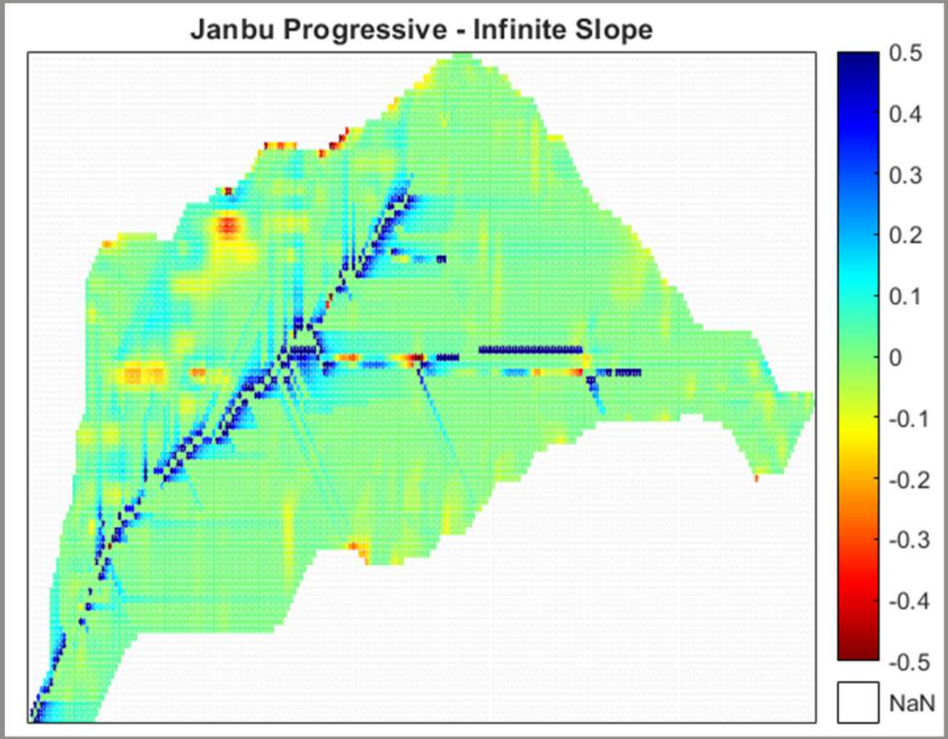
Conclusions

- The Janbu method has been modified for watershed-scale application providing a new slope stability model that overcomes important conceptual limitations of the widely used Infinite Slope (IS) model.

- The method performs better than IS when compared with standard test cases.

- Both models have been implemented inside a distributed hydrological model that provides the transient saturation in every cell of a catchment during a rainfall event.

- The catchment scale application highlights that the IS approach can under- and over-estimate the Factor of Safety for a rainfall event.



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Thanks for your kind attention

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