Rainfall Infiltration and Slope Stability:
A case study in Marumori, Miyagi, Japan

Nilo Lemuel J. Dolojan*, Shuji Moriguchi**, Kenjiro Terada**
*Department of Civil and Environmental Engineering, Tohoku University
**International Research Institute of Disaster Science, Tohoku University

Background

Rainfall is recognized as one of the most common triggers for landslides. In rainfall-induced landslides, failures are typically caused by changes in pore water pressures and/or seepage forces. This study adopts a failure mechanism wherein the soil is in the unsaturated state, and failure is mainly due to rainfall infiltration and loss in shear strength when soil matric suctions are decreased or dissipated.

For this purpose, the Green-Ampt infiltration equation and the infinite slope stability model were utilized in the conduct of the research.

The study area is in Marumori Town, located in Miyagi Prefecture, Japan where numerous landslides occurred during Typhoon 19 "Hagibis" on October 2019


子安地区(廻倉)の土砂災害


あぶくま駅周辺の土石流


五福谷川上流（薄平）

Methodology

Describe the rainfall infiltration behavior (cumulative infiltration, infiltration rate, depth of wetting front) using the Green-Ampt infiltration equations.

- $F(t)_{t+\Delta t} = F(t) + K\cos\alpha\Delta t + \frac{\psi\Delta\theta}{\cos\alpha} \ln\left(\frac{F(t)_{t+\Delta t}\cos\alpha + \psi\Delta\theta}{F(t)\cos\alpha + \psi\Delta\theta}\right)$
- $f(t)_{t+\Delta t} = K\left(\frac{\psi\Delta\theta}{F(t)_{t+\Delta t}} + \cos\alpha\right)$
- $z = \frac{F(t)}{\Delta\theta\cos\alpha}$

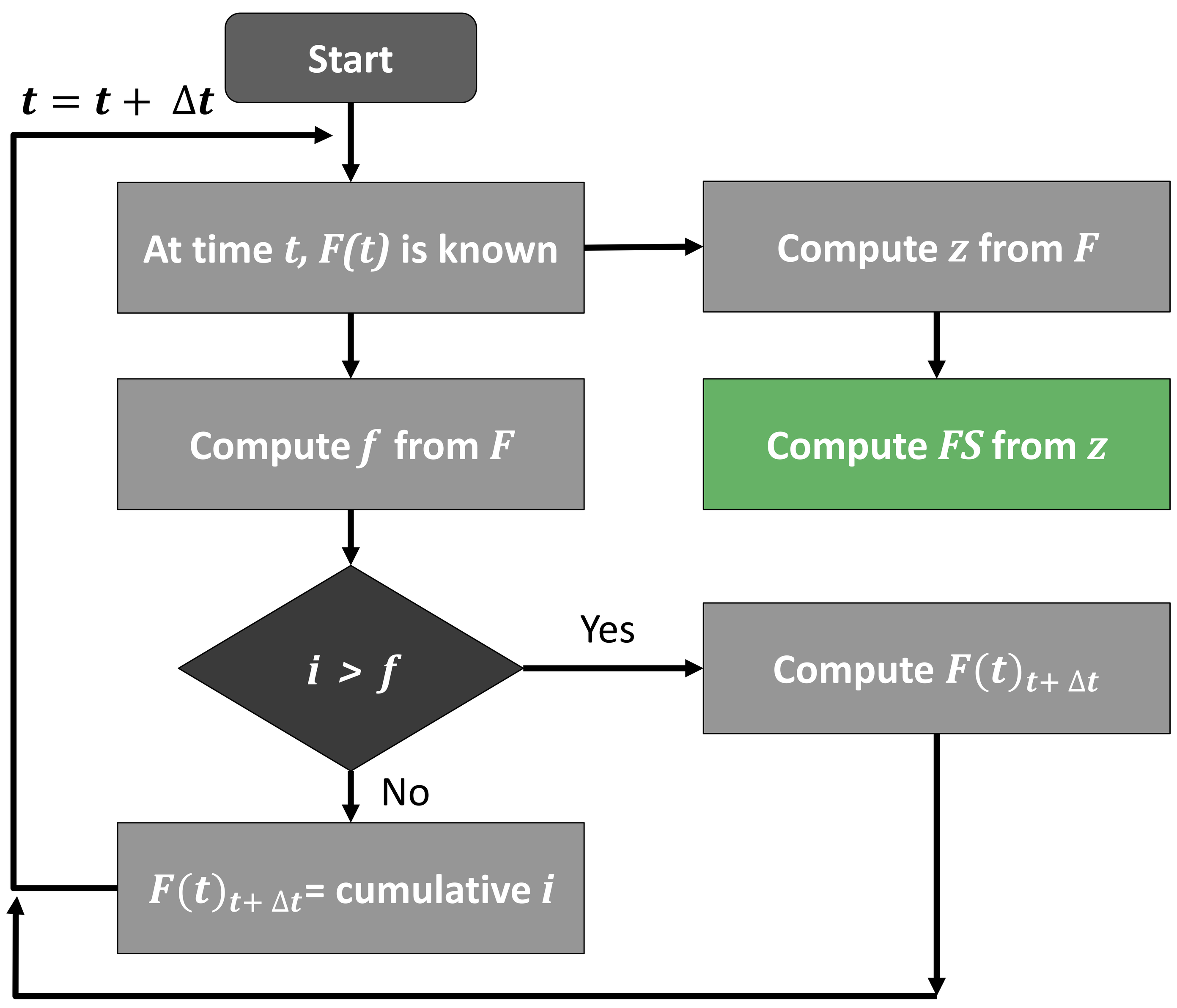
$F(t)$ = cumulative infiltration
$f(t)$ = infiltration rate/capacity
z = wetting front depth
K = hydraulic conductivity
ψ = wetting front soil suction head
$\Delta\theta$ = change in volumetric water content
α = slope angle

Solve for the factor of safety by plugging the depth of wetting front z (from above) into the infinite slope stability equation:

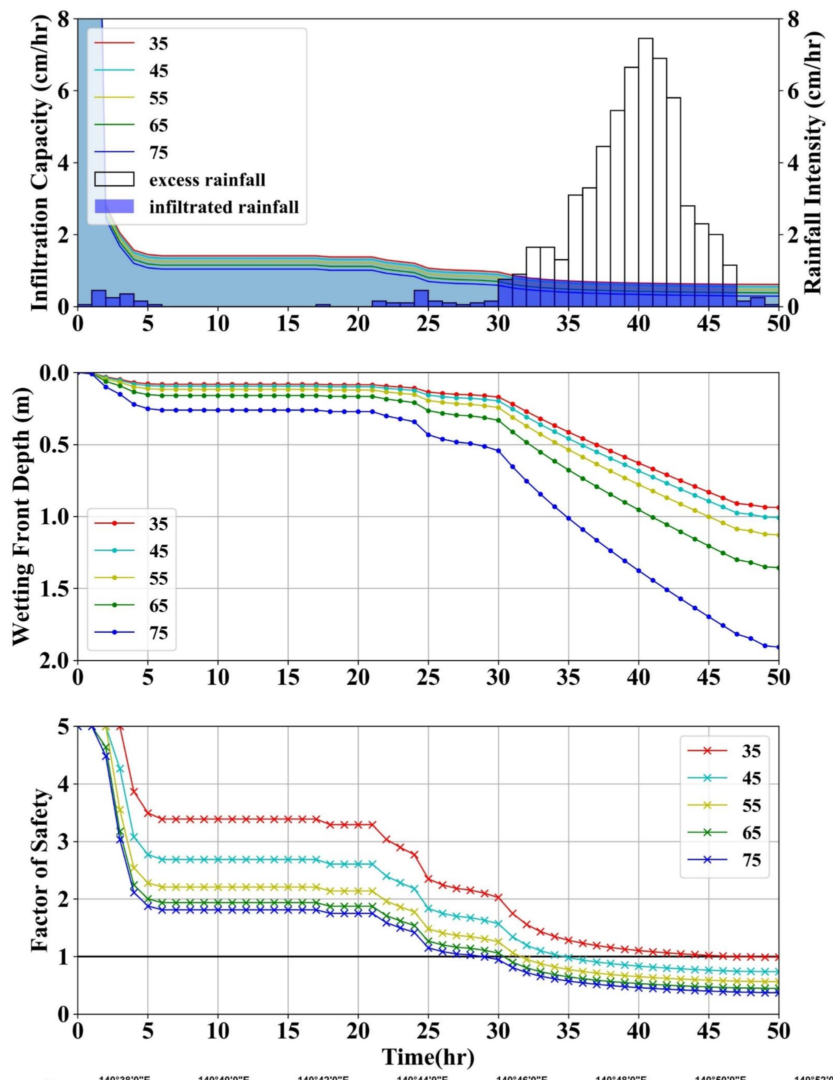
- $FS = \frac{c' + (\gamma_s z\cos^2\alpha + \psi\gamma_w)\tan\phi'}{\gamma_s z\cos\alpha\sin\alpha}$

c' = effective cohesion
ϕ' = effective angle of internal friction
γ_{soil} = unit weight of soil
ψ = wetting front soil suction head
γ_w = unit weight of water

Rasterize and iterate the equations through each grid cell using Python program and ArcGIS software to generate time-series raster grids showing the distribution of factor of safety.

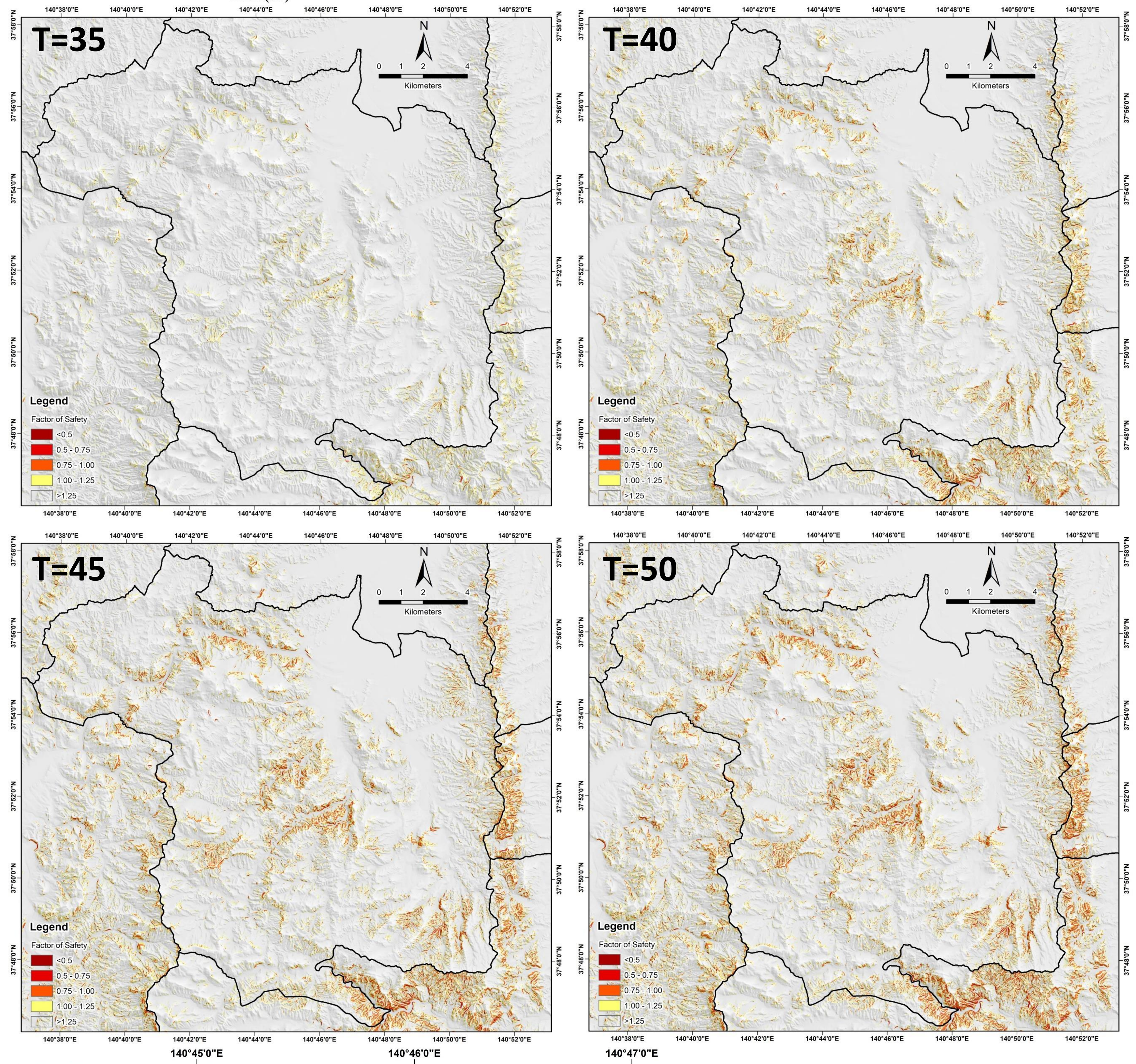


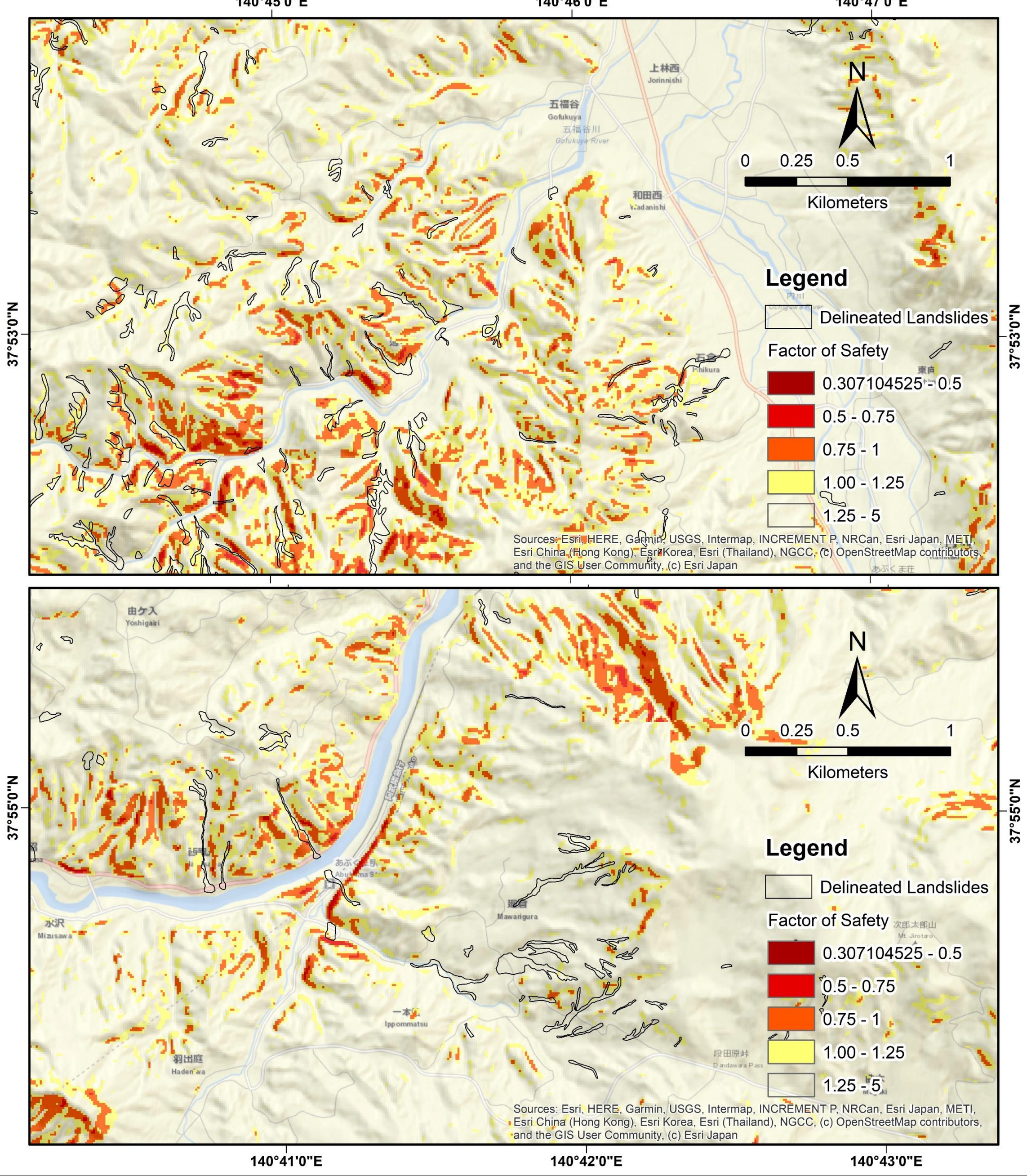
Results



Left: Response of infiltration rate, wetting front depth, and factor of safety with rainfall through time. The plotted lines correspond to slopes of varying angles. The figure shows that for a given time, as the slope angle increases: the wetting front depth increases, while the infiltration capacity and factor of safety decrease.

Below: Visualization map of the computed factor of safety at time t=35, 12Oct2019 14:00; t=40, 12Oct2019 19:00; t=45, 13Oct 2019 00:00; t=50, 13 Oct 2019 05:00. The series of maps depict the progressive decrease in overall stability of the area corresponding to the slopes represented on the factor of safety graph on the left.





Factor of safety map overlain with landslides delineated by the Geospatial Information Authority of Japan. The figure on top is the upstream of Gofukuya River, and the figure below is the area around Abukuma Station. The figure shows reasonable correlation, particularly to source areas, for a slope stability model which utilized a rather simplified approximation of infiltration characteristics whilst neglecting erosion due to surface water runoff.

Conclusion

Through the utilization of a GIS framework, a single point-wise calculation can be rasterized and done simultaneously over multiple points (grid cells). Using the Green-Ampt infiltration and the infinite slope stability models, a visual representation of the overall decline in stability is generated. From this model, the location and time of occurrence of a potential landslide may be estimated. The comparison with actual landslide data gives fair results considering the simplicity and limitations of the model. By using rainfall forecast as input, the model may be extended as an early warning system for unstable slopes during heavy rainfall.