SlideforMap – a regional scale probabilistic model for shallow landslide onset analysis and protection forest management

Feiko van Zadelhoff
Luuk Dorren
Massimiliano Schwarz

contact: Feiko.vanzadelhoff@bfh.ch
Purpose

• predict shallow landslide susceptibility
• Quantify the influence of protection forest regarding shallow landslide hazard
• Regional scale

Why yet another Landslide prediction model?

• Probabilistic parametrization to encompass mountain soil heterogeneity
• Root reinforcement implemented on a tree basis
SlideforMap

Calculations

• Probabilistic

• 100,000s – 10,000,000s randomly located landslides (RLL)

• RLL surface area distribution based on gamma fit on a shallow landslide inventory

• Factor of Safety calculated per RLL
SlideforMap

Input

- DTM & DSM
- Topographic wetness index (TWI) or flow accumulation raster
- A representative landslide inventory
Trees

Summarized Workflow

- DSM minus DTM
- Resample (1 m. res.)
- Gaussian filter (kernel = 3, st. dev. = 2)
- Find Local Maxima and extract height
- DBH = 0.0125 * height
Lateral Root reinforcement

\[ RR_{\text{lat}} (\text{DBH, Distance}) = 50 \cdot \text{DBH} \cdot \gamma[\alpha, \beta] \cdot \frac{\text{Distance}}{0.01 \cdot \text{DBH} \cdot 18.5} \]

\( \alpha \) and \( \beta \): shape and scale parameters of the gamma distribution.

\( \alpha = 5 \)
\( \beta = 15 \)

Moos et al., 2015
Picea Abies (Spruce)
Basal root reinforcement

\[ RR_{bas} = RR_{lat} * \gamma[\alpha,\beta] \text{ (Soil Depth)} \]

\( \alpha = 3.1 \)
\( \beta = 12.57 \)

Moos et al., 2015

Picea Abies (Spruce)

Vegetation Weight

- Trees assumed as cones
- Density assumed of 700 kg/m³
- Weight equally distributed over root extent
Hydrology

TOPmodel (Beven & Kirkby, 1979)

\[ \text{TWI} = \ln \left( \frac{A_{\text{catchment}}}{\tan(\text{Slope})} \right) \]

\[ w = \frac{P}{T} \times \text{TWI} \]

- \( w \) = Fraction of a cell that is saturated i.e. position of groundwater table (-)
- \( P \) = Precipitation (m/s)
- \( T \) = Soil Transmissivity (m³/s)
- \( \text{TWI} \) = Soil Transmissivity (m/s)

Assumed: steady state reached in short time due to macropore dominance in hydrology

The transmissivity is calibrated by assuming that
- Under a precipitation with a 100 year return period
- 25% of the area gets fully saturated (w=1)
Parametrization

Mountainous area -> Probabilistic rather than deterministic -> Picks from a normal distribution for the following parameters:

- Soil Depth (afterwards corrected on steep slopes)
- Soil Cohesion
- Angle of Internal Friction

Deterministic model vs. Mountainous reality

= Rock
= Water table
Each cell is touched by a large number of RLL

Per cell: The percentage of these slides that is unstable (FOS < 1)

Output is:

*Shallow landslide susceptibility under a certain precipitation event*
<table>
<thead>
<tr>
<th>Study Area</th>
<th>Centre (WGS 84)</th>
<th>Size (km²)</th>
<th>Elevation range (m.a.s.l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.81; 46.78</td>
<td>7.54</td>
<td>966 – 1753</td>
</tr>
<tr>
<td>2</td>
<td>7.90; 46.96</td>
<td>1.00</td>
<td>820 – 1016</td>
</tr>
<tr>
<td>3</td>
<td>9.80; 46.98</td>
<td>0.56</td>
<td>1542 – 2009</td>
</tr>
</tbody>
</table>

Landslide inventory from the Swiss Federal office of the environment (BAFU). 667 Shallow Landslides, 1997-2012
= Forest cover (Swisstopo)

= Shallow Landslide
Example of modelled Lateral root reinforcement in Area 1
Event: $P = 38$ mm over one hour

- Observed shallow landslides

Shallow landslide susceptibility (-)
- 25 - 50 %
- 50 - 75 %
- > 75 %
Latin Hypercube Sampling (McKay et al. 1979)

On the fraction of RLL that are unstable.
Mean of 800 runs per test area, only significant variables shown

<table>
<thead>
<tr>
<th>Variable</th>
<th>PRCC (importance of the variable)</th>
<th>Beneficial (+) or harmful (-) to stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral Root reinforcement</td>
<td>0.69</td>
<td>+</td>
</tr>
<tr>
<td>Precipitation event</td>
<td>0.67</td>
<td>-</td>
</tr>
<tr>
<td>Mean Angle of internal friction</td>
<td>0.61</td>
<td>+</td>
</tr>
<tr>
<td>Mean soil depth</td>
<td>0.40</td>
<td>-</td>
</tr>
<tr>
<td>Assumed saturated fraction</td>
<td>0.38</td>
<td>-</td>
</tr>
<tr>
<td>100 year precipitation intensity</td>
<td>0.33</td>
<td>-</td>
</tr>
<tr>
<td>Mean cohesion</td>
<td>0.24</td>
<td>+</td>
</tr>
</tbody>
</table>
## Validation

### AUC

<table>
<thead>
<tr>
<th>Study Area</th>
<th>Mean AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.84</td>
</tr>
<tr>
<td>2</td>
<td>0.84</td>
</tr>
<tr>
<td>3</td>
<td>0.63</td>
</tr>
</tbody>
</table>

### Table

<table>
<thead>
<tr>
<th>Inventory</th>
<th>Model</th>
<th>TRUE</th>
<th>FALSE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TRUE</td>
<td>True positive (TP)</td>
<td>False negative (FN)</td>
</tr>
<tr>
<td></td>
<td>FALSE</td>
<td>False positive (FP)</td>
<td>True negative (TN)</td>
</tr>
</tbody>
</table>

Figure by: Rachel Draelos, Machine learning and medicine
• SlideforMap enables us to predict the effect of different protection forest management techniques, different planting techniques, the influence of forest fires on slope stability and maybe many more applications
Future

- Improvement in the hydrological approach
  somehow make it independent of the topography of the study area, suggestions are welcome

- Improvement in validation

- Differentiate tree species
References


