Multi-criteria decision analysis and GIS modeling for soil erosion vulnerability in the Toplica River Watershed

Tijana Vulevic, Nada Dragovic, Boris Radic
University of Belgrade, Faculty of Forestry, Belgrade, Serbia
tijana.andrijanic@sfb.bg.ac.rs

Soil Erosion Modelling, JRC Ispra, 20-21-22 March 2017
Objective

To rank sub-watersheds in the Toplica river Watershed (Central Serbia) according to soil erosion vulnerability using multi-criteria decision analysis method – PROMETHEE II.
Soil erosion by water is an environmental problem

Consequences
- soil loss
- increase risk of flooding
- siltation of accumulation
- water pollution etc.

Prevention/Mitigations
- reforestation, technical object construction, and other measures.
- On the watershed, sub-watershed scale

Which watershed has a priority?
Study area

Toplica River Watershed (Central Serbia)
A=348.22 km²
PROMETHEE method
(The Preference Ranking Organization METHod for Enrichment Evaluations)

Promethee I
• Partial ranking

Promethee II
• Complete ranking

Qualities: clear method with simple conception and possibilities to check the stability of the results (Brans et al., 1986).
PROMETHEE II

Application steps

1. Establish decision objective, criteria, alternatives and construct an elevation matrix
2. Express weights of decision criteria \( w_j \)
3. Express preference function \( P_j(a,b) \) for each criterion, based on the deviations \( d_j(a,b) \)
4. Calculate global preference index \( \pi(a,b) \)
5. Calculate positive outranking flow \( \varphi^+(a) \) and negative outranking flow \( \varphi^-(a) \)
6. Calculate net outranking flow \( \phi(a) \)

\[
P_j(a, b) = F_j[d_j(a, b)]
\]
\[
\pi(a, b) = \sum_{j=1}^{n} P_j(a, b)w_j
\]
\[
\varphi^+(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a, x)
\]
\[
\varphi^-(a) = \frac{1}{n-1} \sum_{x \in A} \pi(x, a)
\]
\[
\phi(a) = \varphi^+(a) - \varphi^-(a)
\]
Goal: sub-watersheds ranking by soil erosion vulnerability

Criteria: RUSLE factors

- C - factor (Cover-Management)
- K –factor (Soil erodibility)
- R – factor (Rainfall Erosivity)
- LS - factor (Slope Length &Steepness)

Alternatives:
Sub-watersheds in the Toplica River Watershed Ti, i=1,2,..., 11

Sub-watershed delineation
Method: Automatic (DEM based), ArcHydro (Terrain Processing toolset)
Requirements:
DEM (grid cell size = 25m)
HYDROLOGY (stream network in shape file format)
Cover-Management (C – factor)
Cover-Management (C – factor)

Calculated using: CORINA methodology and value of C –factor is adopted from: Panagos et al. (2015), Belanovic et al. (2013) and Diodato et al. (2011)
Soil erodibility (K – factor)
Soil erodibility \((K \text{ factor})\)

Calculated using:
- equation from EPIC model (Williams et al., 1983)
- inputs: soil texture and organic carbon content
Calculated using: Desmet and Govers (1996) equation
(include-contributing area, slope length for grid cell, grid cell size)
Rainfall Erosivity (R - factor)

Calculated using: Grimm et al. (2003) and Van der Knijff et al. (2000) equation (inputs - average annual precipitation)
Preferences, statistics, elevation matrix
(Visual Promethe A.E.)

Elevation matrix

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.68</td>
<td>2.51</td>
<td>925.0</td>
<td>6.56</td>
</tr>
<tr>
<td>2</td>
<td>2.35</td>
<td>3.00</td>
<td>1112.9</td>
<td>6.59</td>
</tr>
<tr>
<td>3</td>
<td>2.74</td>
<td>5.2</td>
<td>972.5</td>
<td>6.37</td>
</tr>
<tr>
<td>4</td>
<td>2.49</td>
<td>6.54</td>
<td>1072.9</td>
<td>5.45</td>
</tr>
<tr>
<td>5</td>
<td>2.88</td>
<td>1.00</td>
<td>730.2</td>
<td>6.54</td>
</tr>
<tr>
<td>6</td>
<td>2.76</td>
<td>1.67</td>
<td>807.0</td>
<td>6.72</td>
</tr>
<tr>
<td>7</td>
<td>2.85</td>
<td>1.86</td>
<td>588.1</td>
<td>6.48</td>
</tr>
<tr>
<td>8</td>
<td>2.86</td>
<td>2.09</td>
<td>624.1</td>
<td>6.22</td>
</tr>
<tr>
<td>9</td>
<td>2.74</td>
<td>1.09</td>
<td>734.3</td>
<td>6.64</td>
</tr>
<tr>
<td>10</td>
<td>2.69</td>
<td>1.07</td>
<td>1114.5</td>
<td>7.14</td>
</tr>
<tr>
<td>11</td>
<td>2.75</td>
<td>1.76</td>
<td>976.6</td>
<td>6.09</td>
</tr>
</tbody>
</table>
The results of sub-watersheds ranking by PROMETHEE II

<table>
<thead>
<tr>
<th>Sub-watershed</th>
<th>Phi</th>
<th>Phi+</th>
<th>Phi-</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0477</td>
<td>0.2482</td>
<td>0.2005</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>0.0189</td>
<td>0.3276</td>
<td>0.3087</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>0.3138</td>
<td>0.4226</td>
<td>0.1088</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>-0.0732</td>
<td>0.3999</td>
<td>0.4731</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>-0.0608</td>
<td>0.2122</td>
<td>0.273</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>-0.0365</td>
<td>0.181</td>
<td>0.2175</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>-0.1316</td>
<td>0.1565</td>
<td>0.2882</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>-0.1425</td>
<td>0.1668</td>
<td>0.3093</td>
<td>10</td>
</tr>
<tr>
<td>9</td>
<td>-0.1948</td>
<td>0.1058</td>
<td>0.3006</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>0.2997</td>
<td>0.4529</td>
<td>0.1531</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>-0.0406</td>
<td>0.1955</td>
<td>0.2361</td>
<td>6</td>
</tr>
</tbody>
</table>

3 > 10 > 1 > 2 > 6 > 11 > 5 > 4 > 7 > 8 > 9
Multiplying R*K*C*LS factors vulnerability to soil erosion for the first order sub-watershed T3 is obtained and classified into 5 classes.

<table>
<thead>
<tr>
<th>Vulnerability of 1st order sub-watershed (T3)</th>
<th>Area [%]</th>
<th>Area [km²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>69.84</td>
<td>29.01</td>
</tr>
<tr>
<td>Low-moderate</td>
<td>5.25</td>
<td>2.18</td>
</tr>
<tr>
<td>Moderate</td>
<td>11.30</td>
<td>4.69</td>
</tr>
<tr>
<td>High</td>
<td>9.04</td>
<td>3.76</td>
</tr>
<tr>
<td>Very high</td>
<td>4.57</td>
<td>1.90</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>41.54</td>
</tr>
</tbody>
</table>
Conclusions

Based on the results, we can conclude that:

- PROMETHEE II outranking method provides a complete ranking of sub-watersheds according to soil erosion vulnerability
- Considered criteria were: land cover, rainfall, soil erodibility and topography
- Using ArcHydro and ArcMap sub-watersheds are generated, layers are produced as well as inputs for evaluation matrix
- Mapping erosion vulnerability using GIS enabled identification of conservation priority area.
- Next step should be: estimate the influence (weights) of RUSLE factors on soil erosion for every sub-watershed and sensitivity analysis of the results of ranking via PROMETHEE method
Thank you