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

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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

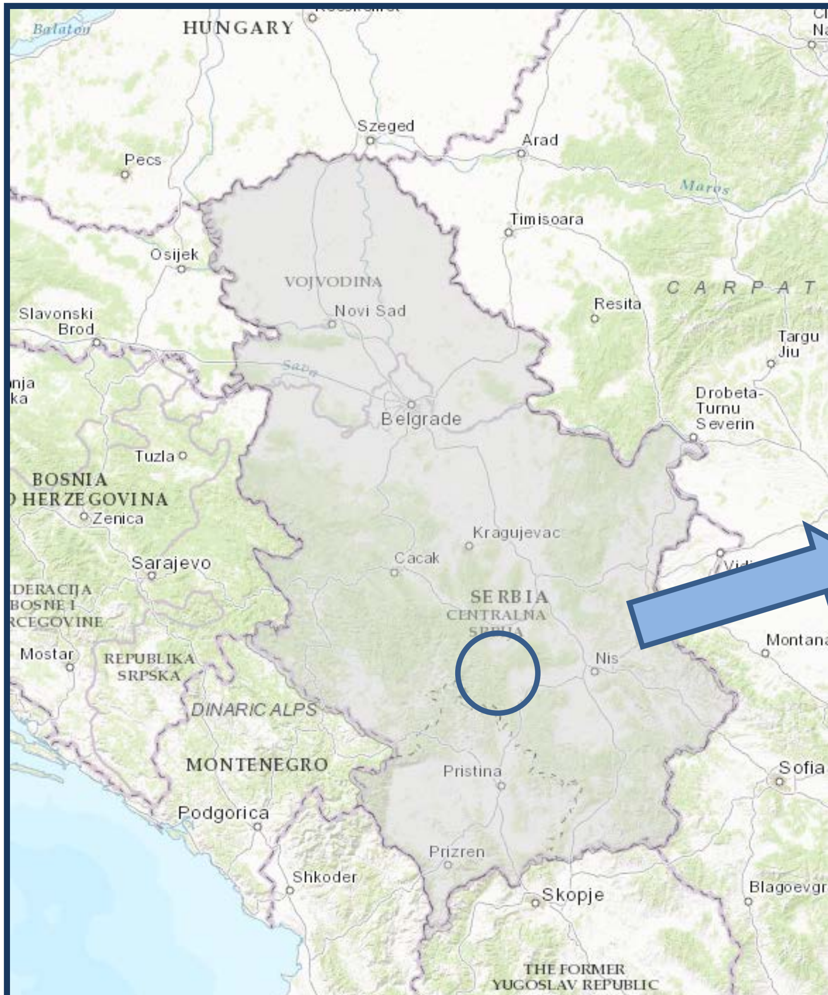
- soil loss
- increase risk of flooding
- siltation of accumulation
- water pollution etc.

Prevention/Mitigations

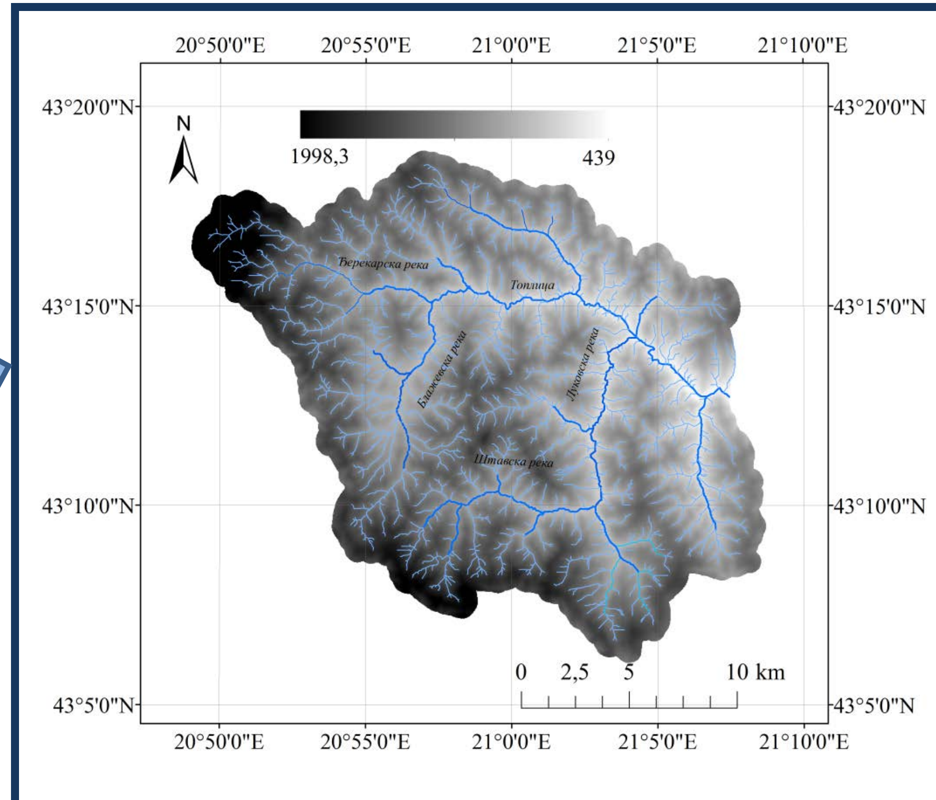
- reforestation, technical object construction, and other measures.
- On the watershed, sub-watershed scale

Which watershed has a priority?

Study area



Toplica River Watershed (Central Serbia)
A=348,22 km^2



PROMETHEE method

(The Preference Ranking Organization METHod for Enrichment Evaluations)

Promethee I

- Partial ranking

Promethee II

- Compleate 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 wj
3. Express preference function Pj(a,b) for each criterion, based on the deviations dj(a,b)
4. Calculate global preference index π(a,b)
5. Calculate positive outranking flow $\varphi^+(a)$ and negative outranking flow $\varphi^-(a)$
6. Calculate net outranking flow φ(a)

$$Pj(a,b) = Fj[dj(a,b)]$$

$$\pi(a,b) = \sum_{j=1}^{n} Pj(a,b)wj$$

$$\varphi^+(a) = \frac{1}{n-1}\sum_{x \in A}\pi(a,x)$$

$$\varphi^-(a) = \frac{1}{n-1}\sum_{x \in A}\pi(x,a)$$

$$\phi(a) = \varphi^+(a) - \varphi^-(a)$$

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

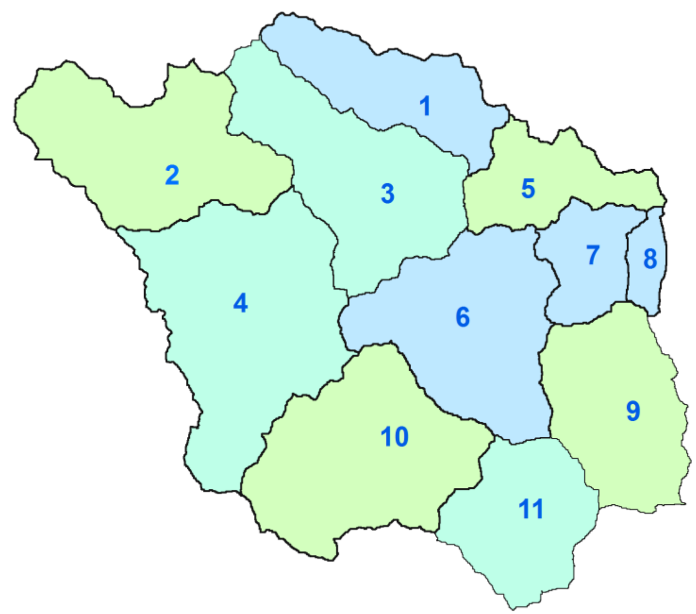
Sub-watershed delineation

Method: Automatic (DEM based), ArcHydro (Terrain Processing toolset)

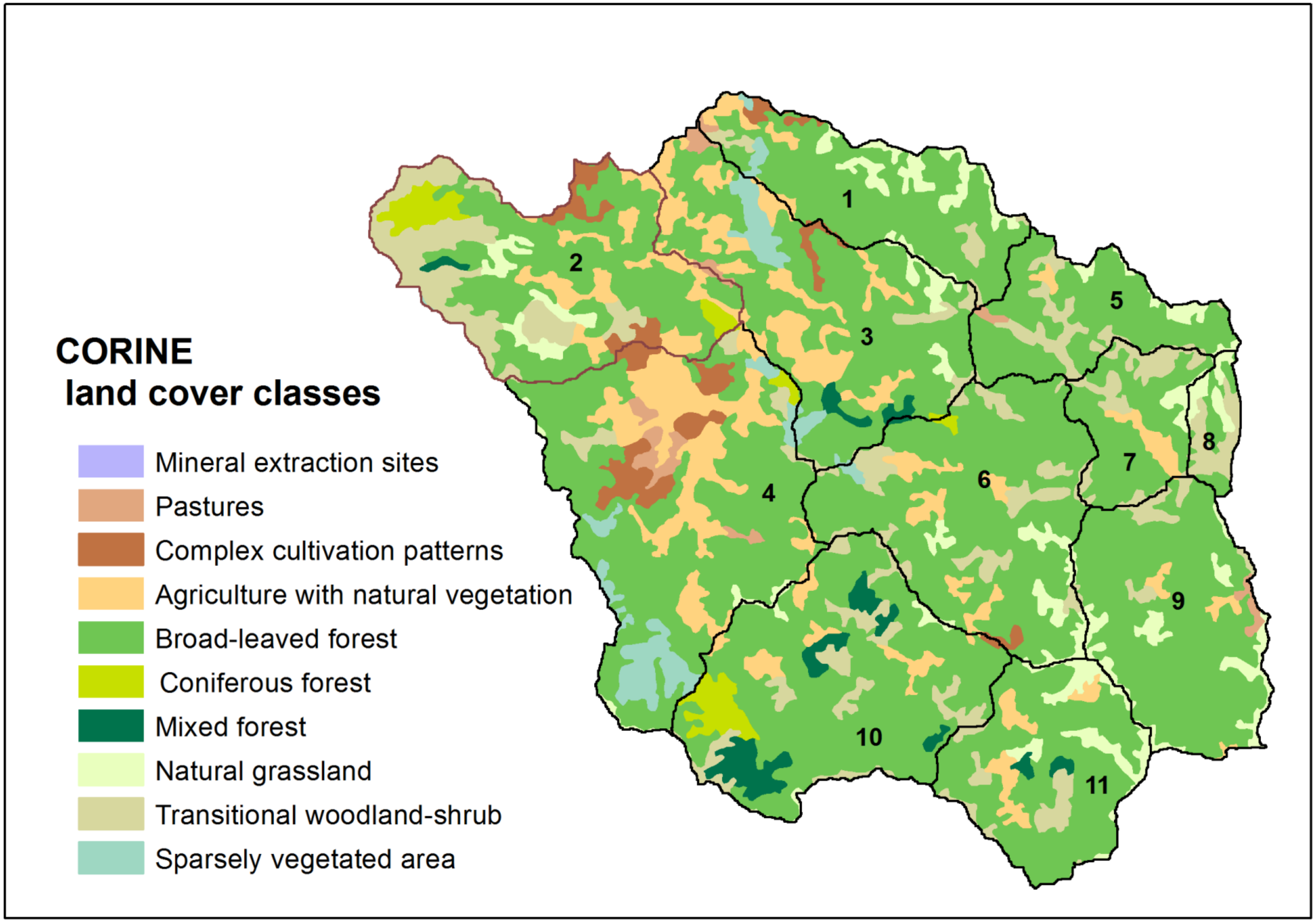
Requirements:

DEM (grid cell size = 25m

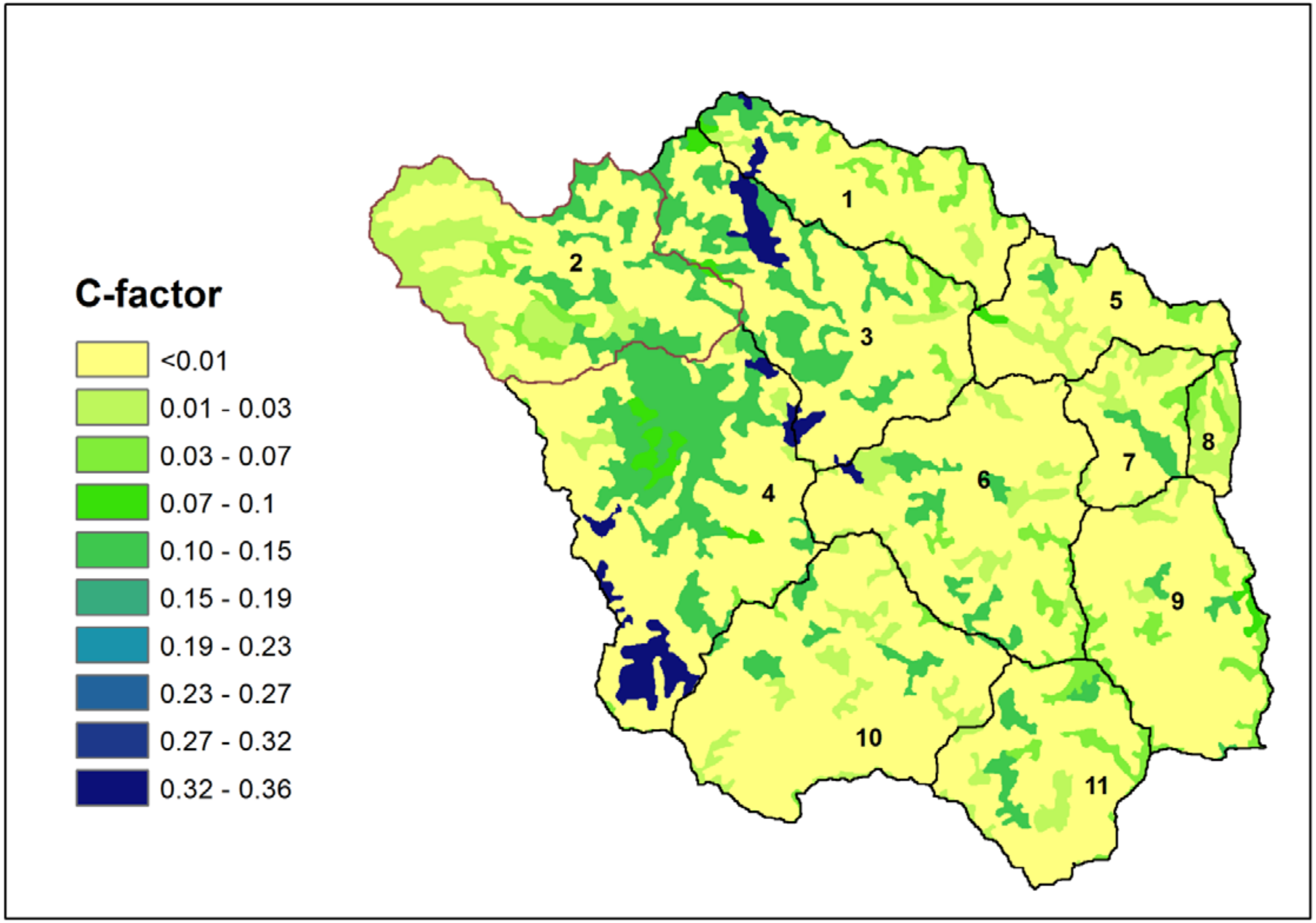
HYDROLOGY (stream network in shape file format



Cover-Management (C – factor)

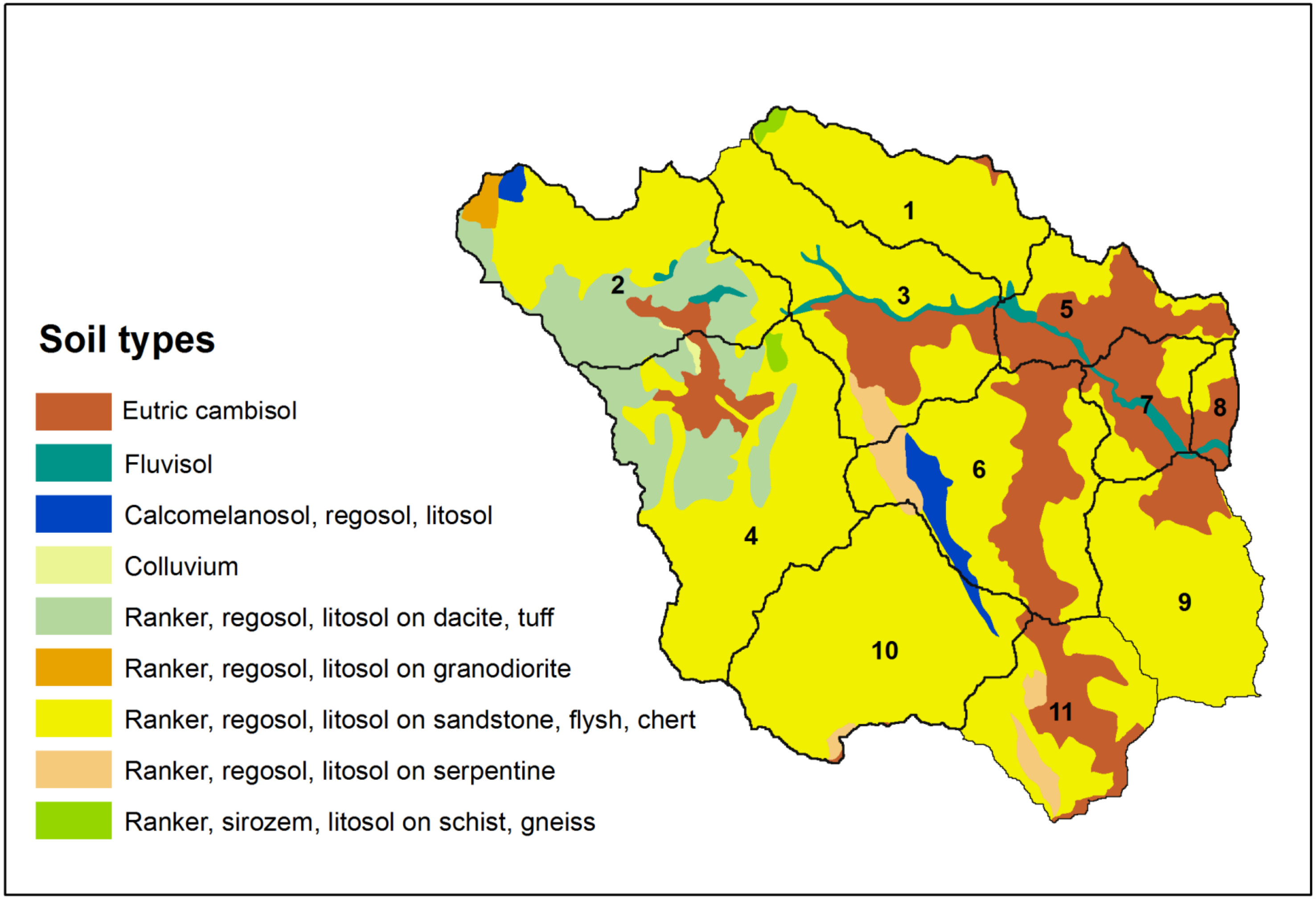


Cover-Management (C – factor)

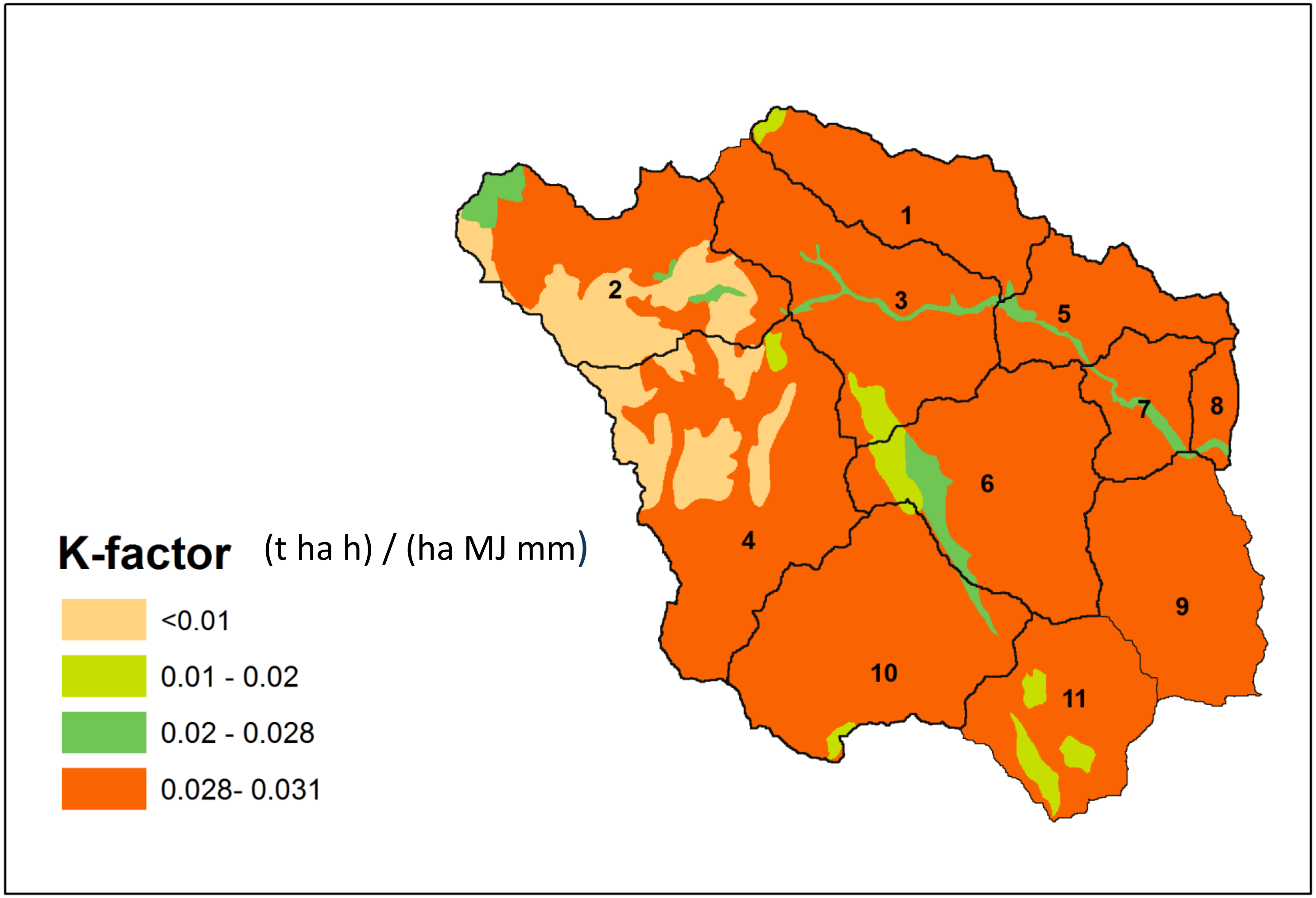


Calculated using: CORINA methodology and value of C –factor is adopted from: Panagos et al. (2015), Belanovic et al. (2013) and Diodato et al. (2011)

Soil erodibility (K – factor)

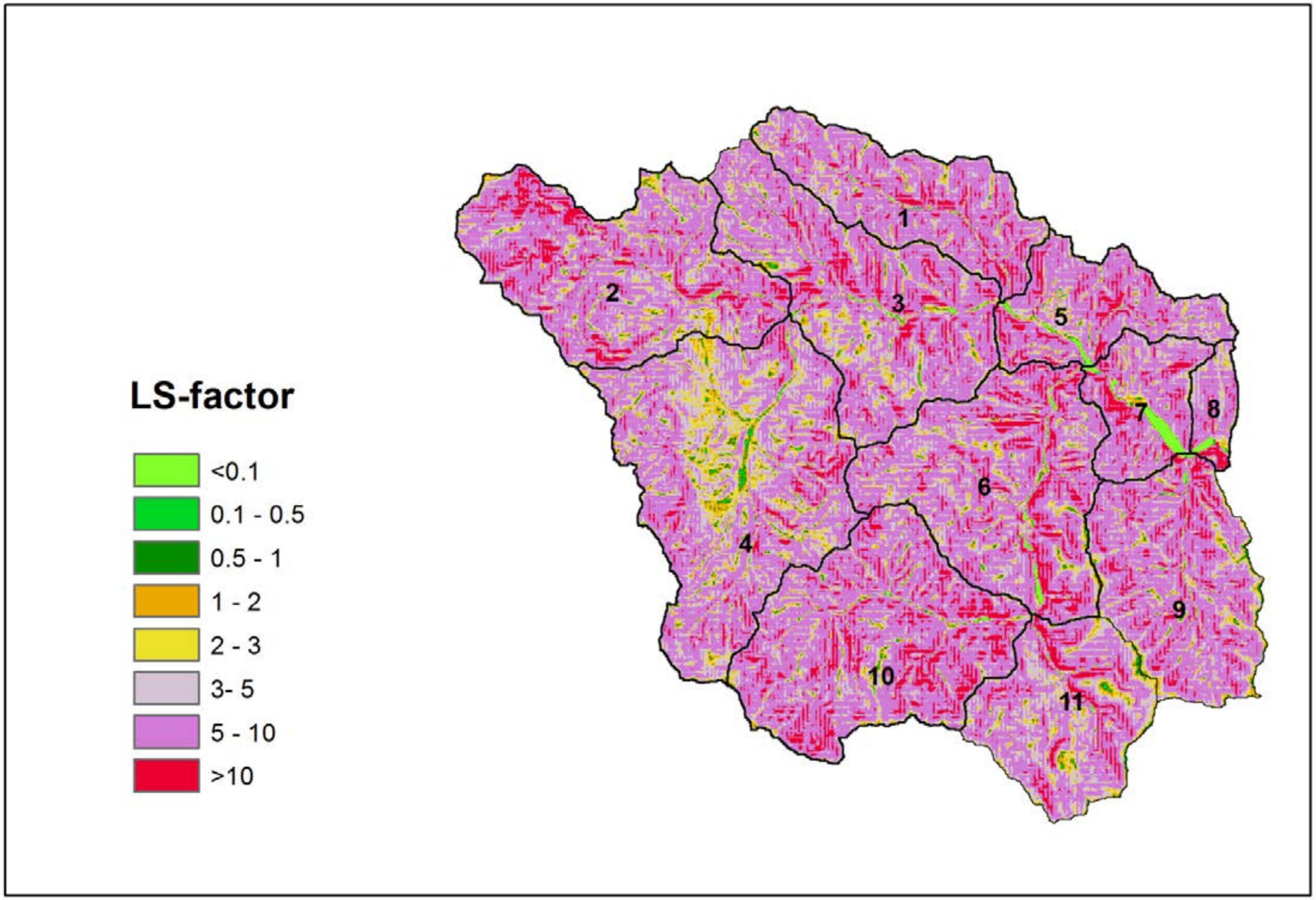


Soil erodibility (K – factor)



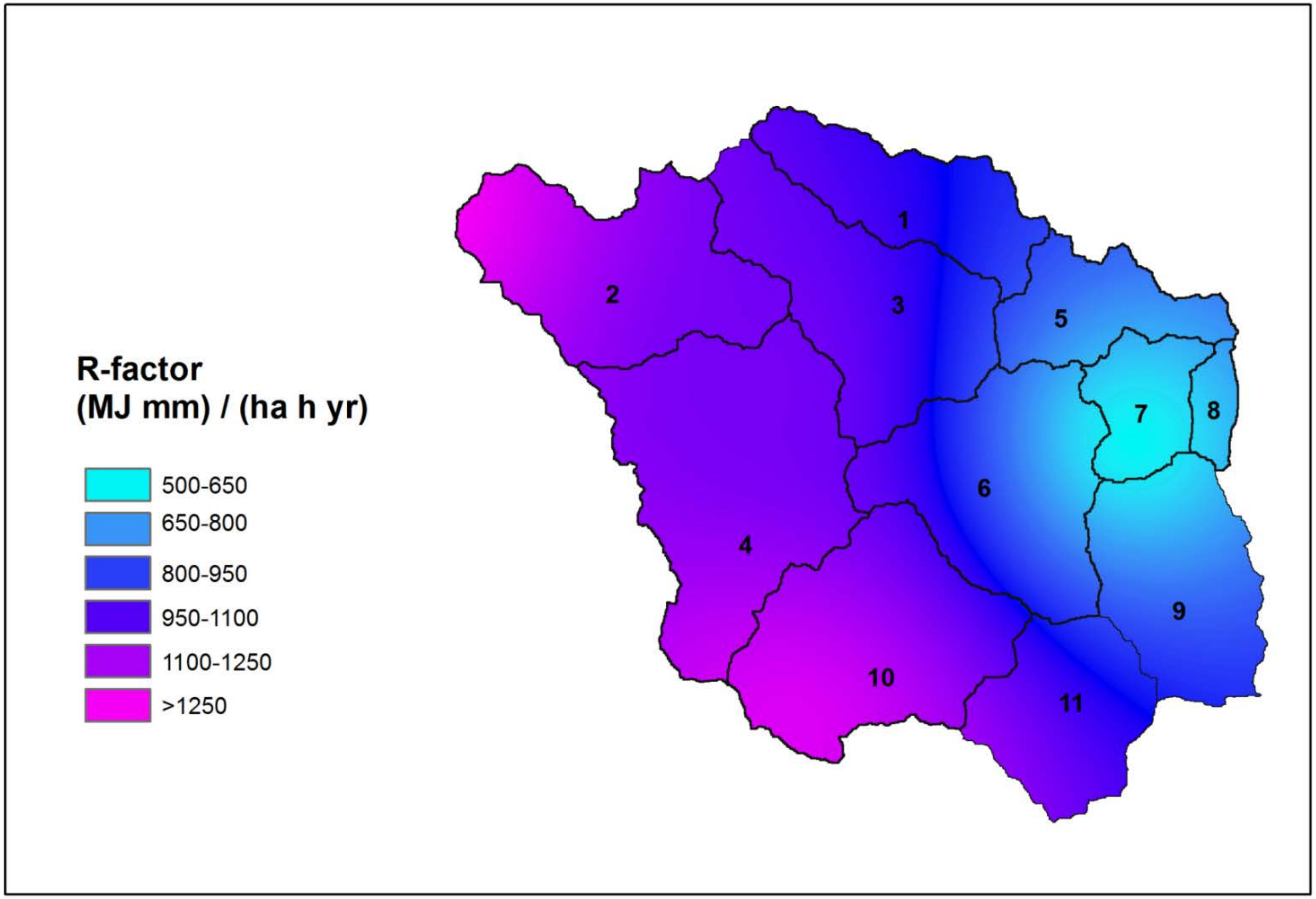
Calculated using: equation from EPIC model (Williams et al., 1983)
(inputs: soil texture and organic carbon content)

Topography (LS - factor)



Calculated using: Desmet and Govers (1996) equation
(include-contributing area, slope lenght 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)

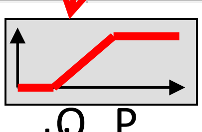
Preferences, statistics, elevation matrix

(Visual Promethe A.E.)

Visual PROMETHEE Academic - Usle.Toplica.w.Linear.vpg (saved)

File Edit Model Control PROMETHEE-GAIA GDSS GIS Custom Assistants Sr

Scenario1	K	C	R	LS
Unit	unit	unit	unit	unit
Cluster/Group	◆	◆	◆	◆
Preferences				
Min/Max	max	max	max	max
Weight	25,00	25,00	25,00	25,00
Preference Fn.	Linear	Linear	Linear	Linear
Thresholds	absolute	absolute	absolute	absolute
- Q: Indifference	0,07	0,69	50,62	0,21
- P: Preference	0,20	2,08	151,86	0,63
- S: Gaussian	n/a	n/a	n/a	n/a
Statistics				
Minimum	2,35	1,00	588,10	5,45
Maximum	2,88	6,54	1114,50	7,14
Average	2,71	2,53	878,01	6,42
Standard Dev.	0,15	1,70	182,41	0,40



Linear

Elevation matrix

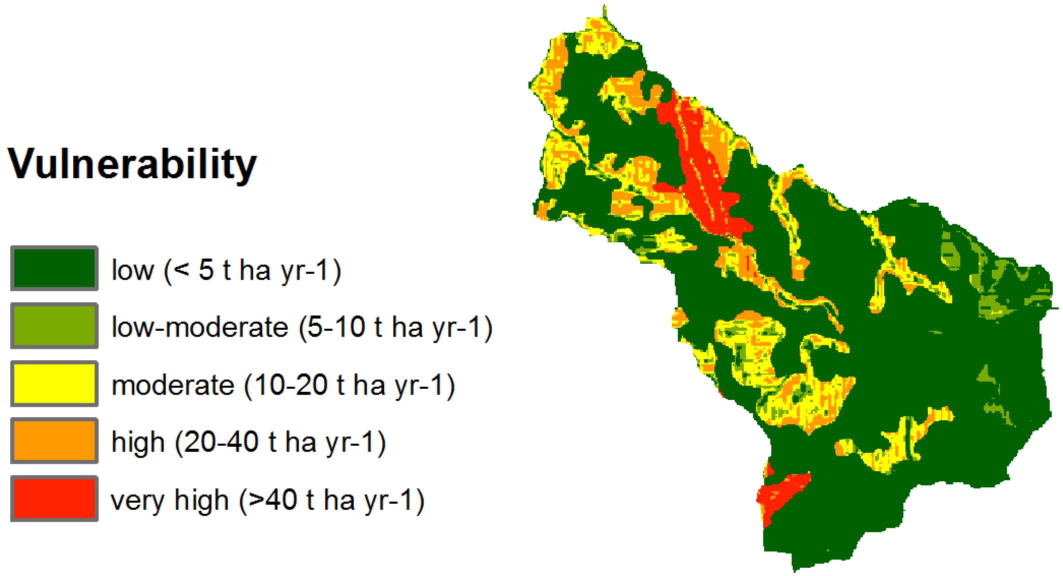
SW	K [10^{-2}]	C [10^{-2}]	R	LS
1	2.68	2.51	925.0	6.56
2	2.35	3.00	1112.9	6.59
3	2.74	5.2	972.5	6.37
4	2.49	6.54	1072.9	5.45
5	2,88	1.00	730.2	6.54
6	2.76	1.67	807.0	6.72
7	2.85	1.86	588.1	6.48
8	2.86	2.09	624.1	6.22
9	2.74	1.09	734.3	6.64
10	2.69	1.07	1114.5	7.14
11	2.75	1.76	976.6	6.09

The results of sub-watersheds ranking by PROMETHEE II

Sub-watershed	Phi	Phi+	Phi-	Rank
1	0,0477	0,2482	0,2005	3
2	0,0189	0,3276	0,3087	4
3	0,3138	0,4226	0,1088	1
4	-0,0732	0,3999	0,4731	8
5	-0,0608	0,2122	0,273	7
6	-0,0365	0,181	0,2175	5
7	-0,1316	0,1565	0,2882	9
8	-0,1425	0,1668	0,3093	10
9	-0,1948	0,1058	0,3006	11
10	0,2997	0,4529	0,1531	2
11	-0,0406	0,1955	0,2361	6

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.



Vulnerability of 1st order sub-watershed (T3)	Area [%]	Area [km^2]
Low	69.84	29.01
Low-moderate	5.25	2.18
Moderate	11.30	4.69
High	9.04	3.76
Very high	4.57	1.90
Total	100	41.54

Consclusions

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