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ASSESSMENT OF RUNOFF AND SOIL EROSION IN THE RADULICKA RIJEKA WATERSHED, POLIMLJE, MONTENEGRO

SUMMARY

Soil erosion is a natural process that is causing environmental concerns such as land degradation, soil loss, water pollution and ecosystem alteration. The Erosion Potential Method (EPM) is extensively used for identifying watersheds with such problems. One of 57 studied river basins of the Polimlje Region was Radulicka Rijeka Watershed where we studied soil erosion processes using the analytical and computer-graphic method IntErO, based on the EPM method. Calculated peak discharge from the river basin was $185 \text{ m}^3 \text{ s}^{-1}$ for the incidence of 100 years and the net soil loss was $13157 \text{ m}^3 \text{ yr}^{-1}$, specific $327 \text{ m}^3 \text{ km}^{-2} \text{ yr}^{-1}$. The use of EPM method and the IntErO model to predict sediment yield, according to our experiences, is recommended for this Region and may also be suitable for making management decisions. At the same time, further research is needed to address model limitations regarding the further development in relation to the GIS adaptations.

Keywords: Erosion, Soil erosion assessment, watershed, Land use, IntErO model.

INTRODUCTION

Sediments play an important role in elemental cycling in the aquatic environment as they are responsible for transporting a significant fraction of nutrients and contaminants. Large suspended sediment fluxes in river catchments, which result from soil loss due to water erosion, constitute a major environmental issue (Louvat *et al.*, 2008). Soil degradation caused by erosion, together with rapid population increase, are ranked as the most important environmental problems in the world (Stoffel and Huggel, 2012), where the erosion is a key driver of land degradation heavily affecting sustainable land management in various environments worldwide (Ballesteros-Cánovas *et al.*, 2015; Al-Turki *et al.*, 2015; Behzadfar *et al.*, 2015; Stoffel *et al.*, 2013; Khaledi Darvishan *et al.*, 2012).

The South and Southeast regions of Europe are significantly prone to water erosion. In Montenegro water erosion is the most important erosion type (Spalevic, 1999). The main forces of water erosion are precipitations and

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consecutive runoff; but not less important is fluvial erosion in water streams (Kostadinov *et al.* 2006).

Water erosion has affected 95% of Montenegro. Alluvial accumulation characterises the remaining area, where the deposition of sediments is also affecting agricultural land. Erosion caused by water is dominant in terrain with high slopes due to complex physical and geographical conditions paired with reckless logging (Spalevic *et al.*, 2015a; Gazdic *et al.*, 2015; Spalevic *et al.*, 2014a; Spalevic *et al.*, 2013a; Spalevic *et al.*, 2013b; Fustic and Spalevic, 2000).

According to Blinkov (2015) the most erosive countries in Europe are the Balkan countries Albania and Montenegro, where the mean annual intensity of erosion is more than 10 t ha^{-1} . This is confirmed by Spalevic *et al.* (2012) for the Mediterranean watersheds of Montenegro: $1900 \text{ m}^3\text{km}^2\text{yr}^{-1}$ for the Zeljeznica river basin of the Adriatic Watershed. On the other hand, for the Polimlje (North of Montenegro, the Black Sea Watershed), the calculated soil losses per km^2 for the 57 river basins were in average $331 \text{ m}^3\text{km}^2\text{yr}^{-1}$ (Spalevic *et al.*, 2015b; Spalevic *et al.*, 2015c; Spalevic *et al.*, 2014b; Spalevic *et al.*, 2014c; Spalevic *et al.*, 2013c; Spalevic *et al.*, 2000).

All stated make clear why erosion risk assessment and its quantification is an important question for this Region.

The idea of this research was the assessment of runoff and soil erosion in the Radulicka Rijeka Watershed, Polimlje, Montenegro, studying spatial characteristics of the various natural phenomena; geological, soil, land use and climate characteristics.

MATERIAL AND METHODS

We studied soil erosion processes in the Radulicka Rijeka Watershed (40 km^2), a right-hand tributary of the river Lim, located in the mountainous area of the Polimlje Region, north of Montenegro (Figure 1).

Morphometric methods were used to determine the slope, the specific lengths, the exposition and form of the slopes, the depth of the erosion base and the density of erosion rills. Google Earth and Google Maps were used for further studying of the morphology of the features.

We used data of geological and pedological research from Zivaljevic (1989), Fustic and Djuretic (2000), who analysed all geological formations and soils of Montenegro including the studied area of the Radulicka Rijeka.

Climatological data were received from the Institute of Hydrometeorology and Seismology of Montenegro (for the period 1948-2015). We analysed torrential rains, annual air temperatures, and average annual precipitations.

Many researchers have attempted to elucidate the interaction between land cover pattern and ecological processes (Fu *et al.*, 2011); and this become the focus of the landscape ecology studies in the field (Casermeiro *et al.*, 2004; Bautista *et al.*, 2007; Fridley *et al.*, 2007; Claessens *et al.*, 2009; Bisigato *et al.*, 2009).

Data in relation to the land use and vegetation cover we received from the Institute of Forestry of Montenegro (IoFoM), Statistical Office of Montenegro (MONSTAT), Google Maps and our own research.

Directly observing large-scale hydrological processes is difficult. Modelling has become a key research tool at the basin scale studies (Fu *et al.*, 2011).

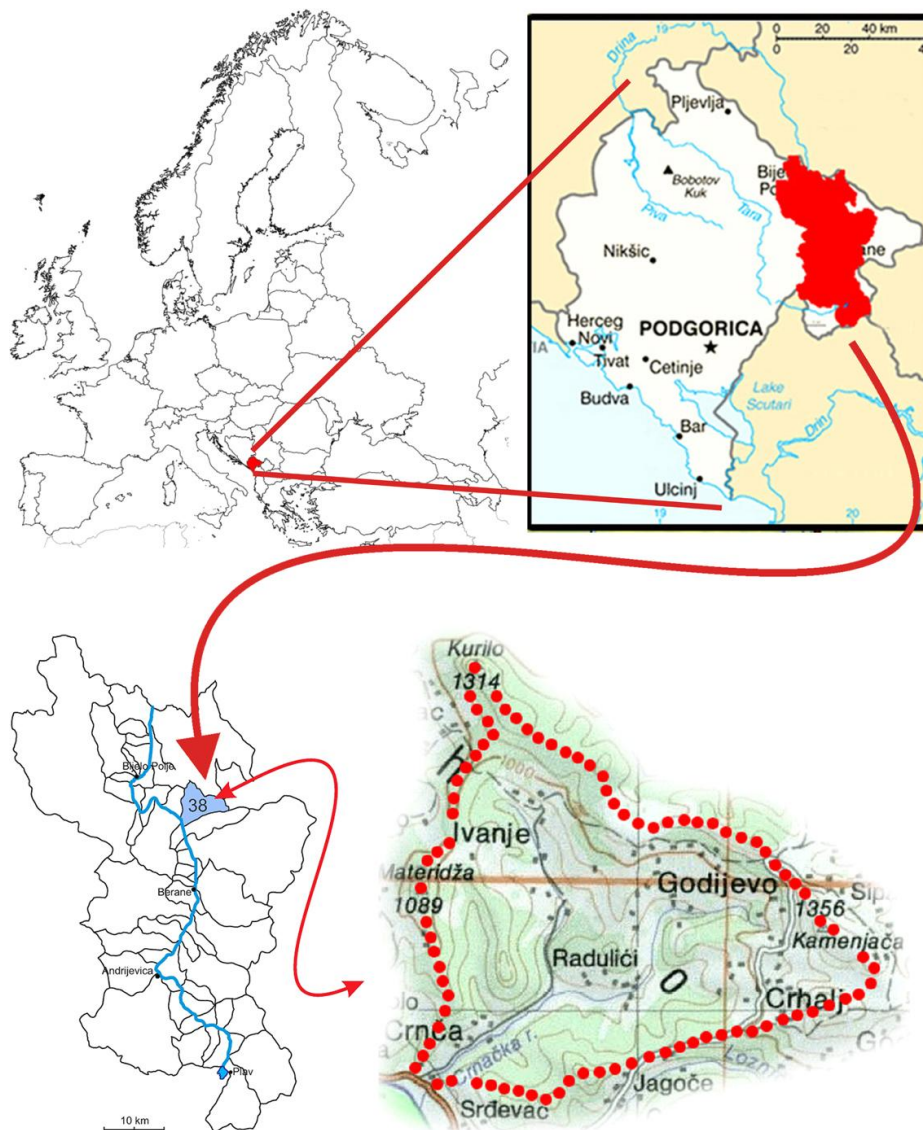


Figure 1. Study area of the Radulicka Rijeka Watershed, Polimlje, Montenegro (H_{min} : 42°57'49.0"N 19°50'29.6"E)

We applied the IntErO model (Spalevic, 2011)² for the assessment of runoff and soil erosion. The analytical equation is the following:

$$W_{yr} = T \cdot H_{yr} \cdot \pi \cdot \sqrt{Z^3} \cdot F$$

where W_{yr} is the annual erosion in $m^3 yr^{-1}$; T, the temperature coefficient; H_{yr} , the average yearly precipitation in mm; Z, the erosion coefficient.

The erosion coefficient, Z, was calculated as follows:

$$Z = Y \cdot X \cdot (\phi + \sqrt{I})$$

where, Y is Soil erodibility coefficient; X is Soil protection coefficient; ϕ is Erosion development coefficient (tables for Y, X and ϕ coefficients available at Gavrilovic, 1972). F is the watershed area in km^2 .

The actual sediment yield was calculated as follows:

$$G_{yr} = W_{yr} \cdot R_u$$

where, G_{yr} is the sediment yield in $m^3 yr^{-1}$; W_{yr} is the total annual erosion in $m^3 yr^{-1}$; R_u is sediment delivery ratio.

The actual sediment yield was calculated as follows:

$$R_u = \frac{(\sqrt{O \cdot D})}{0.2 \cdot (L + 10)}$$

where, O is perimeter of the watershed in km; D is the average difference of elevation of the watershed in km; L is length of the catchment in km.

RESULTS AND DISCUSSION

Climate. The climate in the studied area of the Radulicka Rijeka is continental, with the absolute maximum air temperature of 35°C and negative of 29.8°C. The location of the studied river basin is classified as Dfb by Köppen and Geiger.

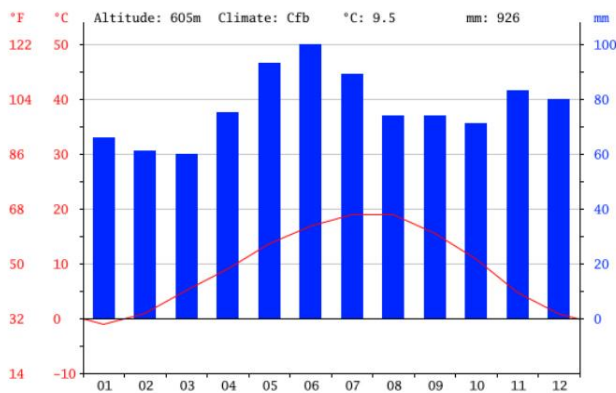


Figure 2. Climate graph (Bijelo Polje)

² The IntErO software available on: www.agricultforest.ac.me/Spalevic/IntErO

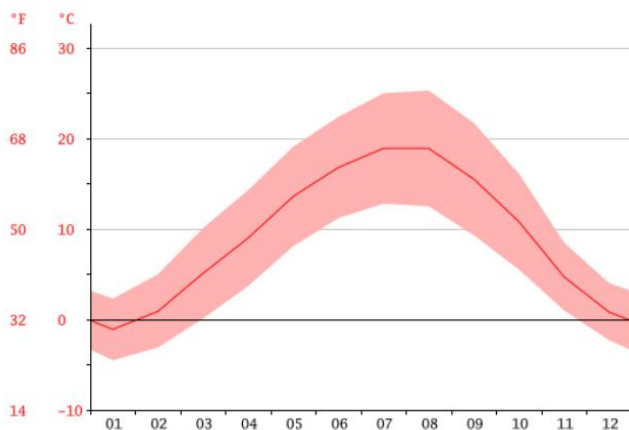


Figure 3. Temperature graph (Bijelo Polje)

The amount of torrential rain, h_b , is calculated on 157.6 mm. The average annual air temperature, t_0 , is 8.9 °C. The average annual precipitation, H_{yr} , is 983.7 mm. The temperature coefficient of the region, T , is calculated to be 0.99.

Geology and soils. The study area belongs to the Durmitor geotectonic unit of the inner Dinarides of Northern and North - eastern Montenegro. The geological structure of that part consists mainly of Paleozoic clastic, carbonate and silicate volcanic rocks and sediments of the Triassic, Jurassic, Cretaceous – Paleogene and Neogene sediments (Frankl *et al.*, 2015).

The coefficient of the region's permeability, S_1 , according to the analysis of geological substrate is calculated on 0.9.

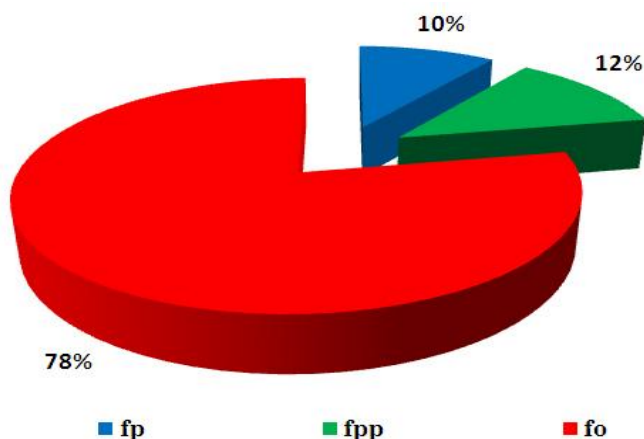


Figure 4: The structure of the river basin, according to bedrock permeability (fp: very permeable; fpp: medium; fo: low permeability).

Based on the results of pedological research (Fustic & Djuretic, 2000; Spalevic, 2011), and our own research, the most common soil types in the watershed are: *Dystric Cambisols* (36.8 km² of the studied river basin), *Eutric Cambisols* (1.2 km²), *Colluvial Fluvisols* (2 km²).

The structure of the river basin, according to the soil types is presented at the Figure 5.

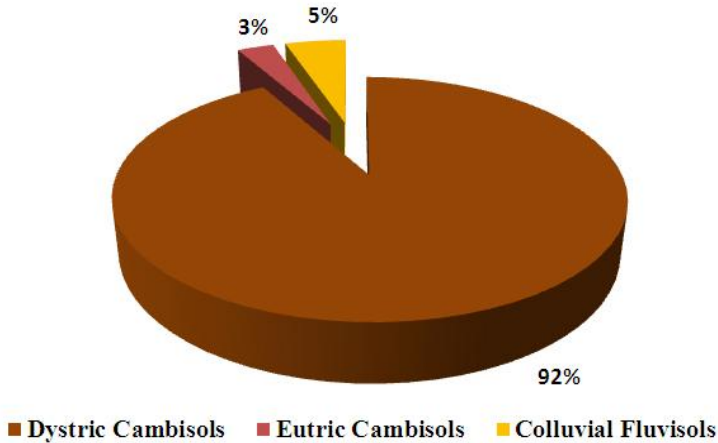


Figure 5: The structure of the river basin, according to the soil types

Land use. The Radulicka Rijeka drainage basin is mainly covered by diverse forms of forests, covering the area of about 50% of the studied river basin. Meadows, pastures and Orchards are covering the area of about 35%. Arable land covers a total surface area of 15%, concentrated in the areas with low slope gradients.

The detailed structure of the river basin, according to the land use is presented at the Figure 6.

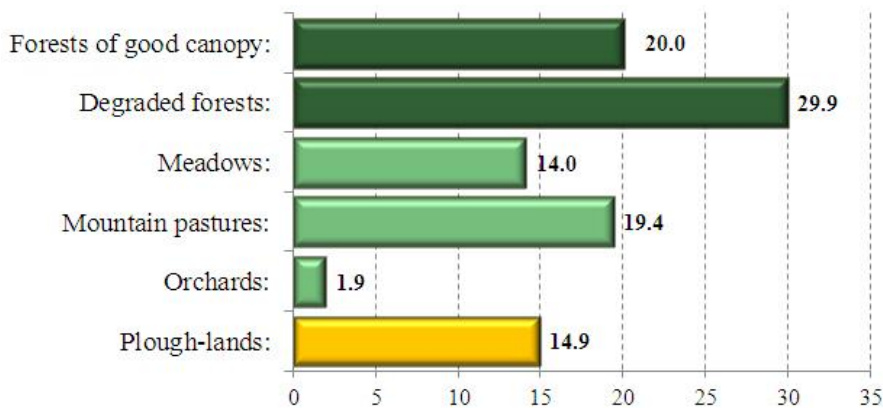


Figure 6: The land use structure of the studied river basin



Figure 7. Details from the studied Radulicka River Basin

Soil erosion characteristics. The dominant erosion form in the studied river basin is sheet erosion. Some problems of overgrazing and livestock traces are recorded also, in the areas close to the village Godijevo and Radulici.

The assessment of runoff and soil erosion in the Radulicka Rijeka Watershed is presented in the Table 1.

Table 1. Part of the IntErO report for the Radulicka Rijeka Watershed

Inputs			
River basin area	F	40.23	km ²
The length of the watershed	O	29.88	km
Natural length of the main watercourse	Lv	8.47	km
The shortest distance (fountainhead and mouth)	Lm	7.08	km
River basin length measured by a series of parallel lines	Lb	12.37	km
The area of the bigger river basin part	Fv	12.17	km ²
The area of the smaller river basin part	Fm	27.78	km ²
Altitude of the first contour line	h0	700	m
The lowest river basin elevation	Hmin	619	m
The highest river basin elevation	Hmax	1356	m
The volume of the torrent rain	hb	157.6	mm
Average annual air temperature	t0	8.9	°C
Average annual precipitation	Hyr	983.7	mm
Types of soil products and related types	Y	1.1	
Coefficient of the river basin planning	Xa	0.51	
Numeral equivalents of visible erosion process	φ	0.31	

Results

Coefficient of the river basin form	A	0.69	
Coefficient of the watershed development	m	0.38	
Average river basin width	B	3.31	km
(A)symmetry of the river basin	a	0.76	
Density of the river network of the basin	G	0.31	
Coefficient of the river basin tortuousness	K	1.2	
Average river basin altitude	Hsr	881.74	m
Average elevation difference of the river basin	D	262.74	m
Average river basin decline	Isr	29.46	%
The height of the local erosion base of the river basin	Hleb	737	m
Coefficient of the erosion energy of the basin's relief	Er	93.15	
Coefficient of the region's permeability	S1	0.9	
Coefficient of the vegetation cover	S2	0.73	
Analytical presentation of the water retention in inflow	W	1.68	m
Energetic potential of water flow during torrent rains	$2gDF^{1/2}$	455.4	m km s
Temperature coefficient of the region	T	0.99	
Coefficient of the river basin erosion	Z	0.497	
Production of erosion material in the river basin	Wyr	43364	m ³ yr ⁻¹
Coefficient of the deposit retention	Ru	0.303	
Real soil losses	Gyr	13157	m ³ yr ⁻¹
Real soil losses per km ²	Gyr (km ²)	327	m ³ km ⁻² yr ⁻¹

CONCLUSIONS

(A)symmetry coefficient indicates that there is a possibility for large flood waves to appear in the river basin. The value of G coefficient of 0.31, indicates there is low density of the hydrographic network. The value of 29.46% indicates that in the river basin prevail steep slopes.

Calculated peak discharge from the river basin was 185 m³s⁻¹ for the incidence of 100 years.

The value of Z coefficient of 0.497 indicates that the river basin belongs to III destruction category; according to the erosion type, it is surface erosion.

The net soil loss was 13157 m³km⁻², specific 327 m³km⁻² per year, what indicates, according to Gavrilovic, that the river basin belongs to V category; region of very weak erosion.

The use of EPM method and the IntErO model to predict sediment yields, according to our experiences, is recommended for this Region and may also be suitable for making management decisions. At the same time, further research is needed to address model limitations regarding the further development in relation to the GIS adaptations.

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