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Velibor SPALEVIC, Dragan RADANOVIC, Morteza BEHZADFAR, Vojislav DJEKOVIC, Aleksandar ANDJELKOVIC, Nedjo MILOSEVIC [1]

CALCULATION OF THE SEDIMENT YIELD OF THE TREBACKA RIJEKA, POLIMLJE, MONTENEGRO

SUMMARY

Soil erosion is global environmental problem which causes land degradation, sedimentation in watercourses, ecological degradation and source pollution. It is important to understand the process of soil erosion in river basins, to categorize the erosion prone areas and find potential measures to alleviate the environmental effects. The main goal of this study was to assess the characteristics of soil erosion and sediment yield of a river basin so that effective conservation measures can be implemented in the studied Region. Ecological factors, which are the basis for the calculation of soil erosion intensity, are included in the IntErO simulation model. The use of computer-graphic methods allowed the quantification of the environmental effects of soil erosion. Data concerning runoff and sediment yield from the Trebacka River basin located in North-East Montenegro are reported. Maximal outflow (incidence of 100 years) from the studied watershed, Q_{max}, was predicted on 170.53 m^3/s. The value of the Z coefficient was calculated on 0.270 and according to the result the watershed belongs in the destruction category IV. The strength of the erosion process is weak, and mixed erosion dominates in the area that has been subject of research. The calculated soil losses were 8622.3 m^3 per year for the watershed, specific 219.39 m^3/km^2 per year. This study has shown that the IntErO model and Erosion Potential Method are useful tools for researchers in calculation of sediment yield at the level of the river basins in the South East European region.

Key words: IntErO model, Erosion Potential Method, soil erosion, sediment yield, watershed, Polimlje

INTRODUCTION

Reduction of soil erosion to preserve soil quality and to maintain land productivity is a major challenge for mountainous soils. Soil erosion can be reduced by appropriate land management. It requires both the collection of field data and the use of predictive model for the evaluation of different management scenarios for the protection of soils (Albaradeyia, 2011). Field measurements of

[1] Velibor SPALEVIC, (corresponding author: velibor.spalevic@ac.me), Biotechnical faculty – Podgorica, University of Montenegro; Dragan RADANOVIC, Delegation of the European Union to Montenegro, Vuka Karadzica 12, Podgorica; Morteza BEHZADFAR, Tarbiat Modares University, Department of Watershed Management, Iran; Vojislav DJEKOVIC, Aleksandar ANDJELKOVIC, Nedjo MILOSEVIC Belgrade University, Faculty of Forestry, Kneza Višeslava 1, 11030 Belgrade, Serbia.

erosion and sedimentation using classical techniques is time-consuming and expensive. The modelling of the erosion process has progressed rapidly, and a variety of models have been developed to predict both the runoff and soil loss (Zhang *et al*. 1996).

In Europe 17% of total land area is roughly estimated to be affected by soil erosion, of which 80% is topsoil loss and 20% terrain deformation (Gobin *et al.*, 2004). Land degradation caused by soil erosion is especially serious in Montenegro. According to Kostadinov *et al.* (2006), water erosion has affected 95% of the total territory of Montenegro.

Quantitative information on soil loss is needed for erosion risk assessment (Spalevic, 2011) and to establish the effectiveness of improved land management practices (Sepulveda *et al.*, 2008). The uses of various indicators that are related to soil erosion are different. Most of these indicators focus, however, on small spatial units, while little attention has been given to the amount of sediment exported at the catchment scale. Small spatial unit approach neglects the transfer of sediment through catchments as well as the scale-dependency of erosion processes. Furthermore, small spatial unit approach does not consider important off-site impacts of soil erosion, such as sediment deposition in reservoirs, flooding and ecological impacts (Vanmaercke *et al*, 2011). This was the reason why the authors of this study approach this problem on catchment scale.

This approach requires the collection of field data, various measurements, and processing of those data through the predictive models for the evaluation of different management scenarios for the soil conservation. Field measurements of erosion and sedimentation using classical techniques are time-consuming and expensive.

The objective of this paper is to study soil erosion processes applying the IntErO model (Spalevic, 2011), with the Erosion potential analytical method (Gavrilovic, 1972) embedded in the algorithm of this computer-graphic method, simulating runoff and sediment yield for a Trebacka river basin of Polimlje. The important results of this study are the determination of erosion processes, and new particular information about the recent state of the runoff as well as a sediment yield in formats that can facilitate its efficient management and protection, illustrating the possibility of modelling of sediment yield with such approach.

MATERIAL AND METHODS

Study area. We studied the area of the Trebacka River basin that encompasses an area of 39.4 km^2, with the length of the watershed of 34.9 km. It is a part of the natural entity of the Polimlje region. The shortest distance between the fountainhead and the mouth, Lm, is 12.63 km. The total length of the main watercourse, with tributaries of I and II class, ΣL, is 16.43 km.

Fieldwork and laboratory analysis. Fieldwork was undertaken to collect detailed information on the intensity and the forms of soil erosion, the status of plant cover, the type of land use and the measures in place to reduce or alleviate the erosion processes. 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.

Some pedological profiles had been opened, and soil samples were taken for physical and chemical analysis. The granulometric composition of the soil was determined by the pipette method (Gee and Bauder, 1986; Karkanis *et al*. 1991); the soil samples were air-dried at 105°C and dispersed using sodium pyrophosphate. The soil reaction (pH in H2O and nKCl) was determined with a potentiometer. Total carbonates were determined by the volumetric Scheibler method (Thun and Herrmann, 1949); the content of the total organic matter was determined by the Kotzman method (Jakovljevic *et al*. 1995); easily accessible phosphorous and potassium were determined by the Al-method (Egner *et al*. 1960), and the adsorptive complex (y1, S, T, V) was determined by the Kappen method (Kappen, 1929).

Figure 1: Study area

Soil loss model application. Blinkov and Kostadinov (2010) evaluated applicability of various erosion risk assessment methods for engineering purposes. Factors taken into consideration depended on scale, various erosion tasks as well as various sector needs. The Erosion potential method (EPM) was, according to them, the most suitable on catchment level for the watershed management needs in this Region.

The analytical equation for the calculation of the annual volume of detached soil due to surface erosion is as follows:

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

where,
W_{year} is the total annual erosion in $m^3 year^{-1}$;
T is the temperature coefficient;
H_{year} is the average yearly precipitation in mm;
Z is the erosion coefficient
where,
$Z = Y \cdot X \cdot (\phi + \sqrt{I})$
where,
Y is Soil erodibility coefficient (table with values available at Gavrilovic, 1972);
X is Soil protection coefficient (table with values available at Gavrilovic, 1972);
ϕ is Erosion development coefficient (table available at Gavrilovic, 1972);
F is the watershed area in km^2.

The actual sediment yield was calculated as follows:

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

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

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

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.

This method is in use also in Bosnia & Herzegovina, Croatia, Italy, Iran, Montenegro, Macedonia, Serbia and Slovenia, as well as in some countries of Central and East Europe: Czech Republic and Bulgaria (Kostadinov *et al*., 2014). The EPM is distinguished by its high degree of reliability in calculating sediment yields as well as transport and reservoir sedimentation (Ristic *et al.*, 2011).

The method was first calibrated in Serbia (Gavrilovic, 1972) and also validated for the Polimlje region in the period from 1999 to 2011 using the observed/measured sediment yield values from the Potpec accumulation on the river Lim (Spalevic, 2011).

The use of computer-graphics in research on runoff and the intensity of soil erosion have been demonstrated in Montenegro, specifically in the Region of Polimlje (Spalevic, 2011). That approach was used in the research on the river basin of Trebacka Rijeka. We used the Intensity of Erosion and Outflow (IntErO) program package (Spalevic, 2011) to obtain data on forecasts of sediment yield and maximum runoff from the basin. EPM is embedded in the algorithm of this computer-graphic method.

RESULTS AND DISCUSSION

Physical-geographical characteristics and erosion factors. Many authors have studied the physical-geographical characteristics of this area. Cvijic (1921) called attention to the geographical individuality of the Region. Knezevic and Kicovic (2004) described the natural characteristics; Pavicevic (1956, 1957), Pavicevic and Antonovic (1976) and Spalevic (1999a, 2011) characterised erosion processes of the upper part of the Polimlje Region.

The river basin of Trebacka River stretches from its inflow to Lim, where Hmin, is 721 m, to the tops of the Lumer, and Lisa, where the Hmax is 1876 m. There is a flat area on the lower alluvial terrace, close to the inflow of Trebacka River to the river Lim, in the village of Trepca, and steep slopes in the upper part of the river basin on the slopes of Rudo Brdo (1640 m.a.s.l.) and Lisa, on the south, Backo Brdo (1678 m.a.s.l.), on the east, as well as Vranja Glava (1779 m.a.s.l) and Zminja Glava (1733 m.a.s.l) on the north. The average slope gradient in the river basin, Isr, is calculated on 35.66% and indicates that in the river basin prevail very steep slopes. The average river basin altitude, Hsr, is 1440.84 m; the average elevation difference of the river basin, D, is 719.84 m.

Climatic characteristics. The area is characterised by dry summers; rainy autumns and springs; and cold winters. The absolute maximum air temperature is 35^{O}C. Winters are severe, so much so that negative temperatures can fall to a minimum of -29.8^{O}C. In terms of rainfall, there are two characteristically rainy periods of the year: the first-cold period (October-March) and the second-warm period (April-September). The amount of torrential rain, hb, is 62.3 mm. The average annual air temperature, t0, is 9 °C. The average annual precipitation, Hyear, is 1183 mm.

The geological structure of the area. In the structural-tectonic sense, the studied area belongs to the Durmitor geotectonic unit of the inner Dinarides of Northern and North-eastern Montenegro (Zivaljevic, 1989). The geological structure of that part of Montenegro consists mainly of Paleozoic clastic, carbonate and silicate volcanic rocks and sediments of the Triassic, Jurassic, Cretaceous-Paleogene and Neogene sediments and Quaternary.

The coefficient of the region's permeability, S1, is calculated on 0.9.

Soil characteristics of the area. Pavicevic (1956, 1957), Pavicevic and Tancic (1970), Fustic and Djuretic (2000), and Spalevic (2011) studied the soils of the Upper Polimlje. The most common soil type is Brown district (acid) soils, on sandstones, granite, gneiss (89%). In some smaller areas in the river basin there are also soils such as Rankers (9%), resting on bedrock within 30 cm depth; Alluvial-deluvial soils (2%) close to the inflow of Trebacka River to Lim.

Vegetation. Overall, vegetation cover has strongly increased in Montenegro. The industrialisation that expanded in the 1950s led to strong urbanisation. Despite steadily increasing population (with the notable exception of the mountain region), the vegetation cover has increased markedly everywhere. This denser vegetation has led to higher infiltration of rainfall (Nyssen *et al*., 2012).

Most of the studied river basin is covered by low beech forests (*Fagetum montanum*). Beech forests are characterized by low share of high quality wood (Curovic *et al* 2011). On the southern exposures there are forests of Common oak (*Sessile oak*) and Turkish oak (*Quercetum petraeae-cerridis*). A narrow belt near the river in the lower part of the river basin is covered with hygrophilic forest (*Alnetea glutinosae, Salicetea herbacea*). The upper part of the basin includes mixed forests of broadleaves and deciduous tree species (*Abieti - Fagetum moesiacae*) and conifer forests of fir and spruce (*Picetum excelsae montanum*). At the highest altitudes of the basin there are subalpine forests of beech, as well as those of subalpine forests of spruce with junipers.

Trebacka Previja (1108 m.a.s.l.)

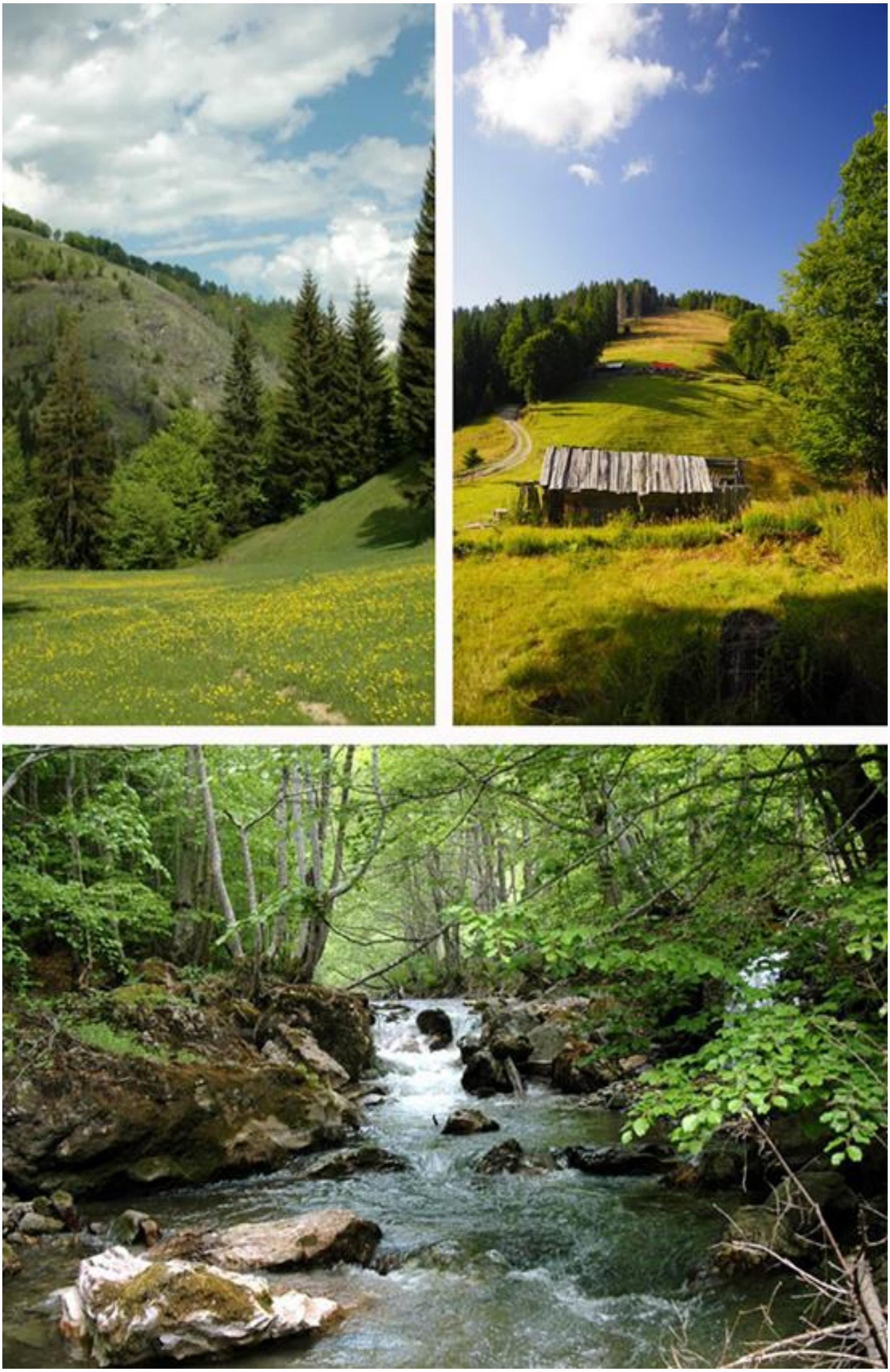

Figure 2: Gradisnjica, Trebacka Rijeka in the upper part of the river basin

According to our analysis, portion of the river basin under forest cover is 70.66%; grass, meadows, pastures and orchards covering 28.99%; bare land, ploughed land and ground without grass vegetation 0.35%. The coefficient of the river basin planning, Xa, is 0.28.

Of the total river basin area, related to the river basin structure, well-constituted forests are the most widespread form (52.39%). Degraded forests covered an area of 18.27%, Meadows 14.84%, Mountain pastures, 14.02%, Ploughed lands 0.35% and Orchards 0.13%. The coefficient of the vegetation cover, S2, is 0.66.

Structure of land use in the Trebacka River Basin is presented in Figure 8.

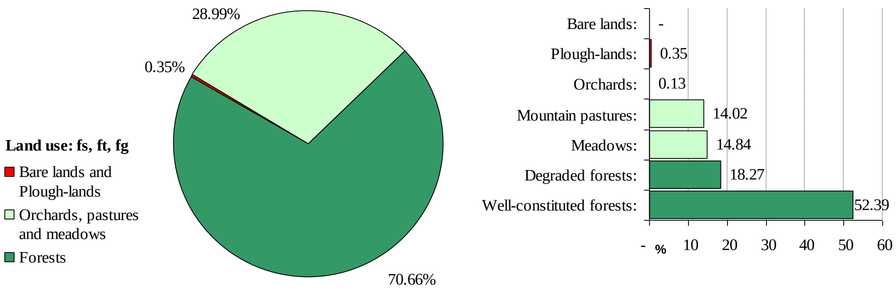

Figure 8. Land use structure of the Trebacka River Basin

IntErO model for soil loss modelling. Soil erosion represents key environmental issues worldwide (Stoffel and Huggel, 2012) and major initiator of land degradation (Verheijen *et al*., 2009). Water-induced soil erosion is the result of the complex effect of a whole group of factors. In their research, Curovic *et al.* (1999), Popovic *et al.* (1999, 2000), Fustic and Spalevic (2000), Spalevic *et al.* (2001), Spalevic *et al.* (2008), Spalevic (2011), Djekovic *et al.* (2013) showed that erosion intensity is always influenced by the properties and the use of soil, increasingly so in the anthropogenous period of their evolution.

We used the software IntErO to process the input data required for calculation of the sediment yield and runoff. A report for the Trebacka River basin is presented in Table 1.

Table 1. IntErO report for the Trebacka River basin

Input data			
River basin area	F	39.3	km²
The length of the watershed	O	34.96	km
Natural length of the main watercourse	Lv	13.83	km
The shortest distance between the fountainhead and mouth	Lm	12.63	km
The total length of the main watercourse (tributaries of I & II class)	ΣL	16.43	km
River basin length measured by a series of parallel lines	Lb	15.95	km
The area of the bigger river basin part	Fv	25.21	km²
The area of the smaller river basin part	Fm	14.09	km²
Altitude of the first contour line	h0	800	m
Equidistance	Δh	100	m
The lowest river basin elevation	Hmin	721	m
The highest river basin elevation	Hmax	1876	m
A very permeable products from rocks (limestone, sand, gravel)	fp	0.13	
A part of the river basin area consisted of medium permeable rocks	fpp	0.05	

A part of the river basin consisted of poor water permeability rocks	fo	0.81	
A part of the river basin under forests	fš	0.71	
A part of the basin under grass, meadows, pastures and orchards	ft	0.29	
A part of the basin under bare land, plough-land and without grass	fg	0	
The volume of the torrent rain	hb	62.3	mm
Incidence	Up	100	years
Average annual air temperature	t0	9	°C
Average annual precipitation	Hgod	1183.7	mm
Types of soil products and related types	Y	1.1	
River basin planning, coefficient of the river basin planning	Xa	0.28	
Numeral equivalents of visible and clearly exposed erosion process	φ	0.27	
Results:			
Coefficient of the river basin form	A	0.49	
Coefficient of the watershed development	m	0.62	
Average river basin width	B	2.46	km
(A)symmetry of the river basin	a	0.57	
Density of the river network of the basin	G	0.42	
Coefficient of the river basin tortuousness	K	1.1	
Average river basin altitude	Hsr	1440.79	m
Average elevation difference of the river basin	D	719.79	m
Average river basin decline	Isr	35.88	%
The height of the local erosion base of the river basin	Hleb	1155	m
Coefficient of the erosion energy of the river basin's relief	Er	146.84	
Coefficient of the region's permeability	S1	0.9	
Coefficient of the vegetation cover	S2	0.66	
Analytical presentation of the water retention in inflow	W	0.7796	m
Energetic potential of water flow during torrent rains	2gDF^½	744.99	m km s
Maximal outflow from the river basin	Qmax	170.53	m³/s
Temperature coefficient of the region	T	1	
Coefficient of the river basin erosion	Z	0.271	
Production of erosion material in the river basin	Wgod	20483	m³/god
Coefficient of the deposit retention	Ru	0.421	
Real soil losses	Ggod	8622.3	m³/god
Real soil losses per km2	Ggod/km²	219.39	m³/km² god

Coefficient of the river basin form, A, is calculated on 0.49; Coefficient of the watershed development, m, on 0.62. Average river basin width, B, is 2.46 km. (A)symmetry coefficient, calculated on 0.57, indicates that there is a possibility for large flood waves to appear in the river basin. The value of G coefficient of 0.42 indicates there is low density of the hydrographic network.

Coefficient of the river basin tortuousness, K, is 1.10. Coefficient of the erosion energy of the river basin's relief, Er, is 146.84.

Maximal outflow from the river basin, Q_{max}, is 170 m^3s^{-1}. The dense vegetation has led to higher infiltration of rainfall. Partitioning of water led, on one hand, to deep infiltration and better low flows and to increased evapotranspiration at the boundary layer, leading to decreased total runoff coefficients. In the mountain region of Montenegro, runoff coefficients have increased, which may be related to earlier snowmelt (Nyssen *et al.*, 2012).

The value of Z coefficient of 0.270 indicates that the river basin belongs to IV destruction category. The strength of the erosion process is weak, and mixed erosion dominates in the studied area.

Production of erosion material in the river basin, W_{year}, is calculated in 20483 m^3 $year^{-1}$; Coefficient of the deposit retention, Ru, on 0.421. Real soil losses, G_{year}, are 8622.32 m^3 $year^{-1}$, specific, per km^2, G $_{year}$ km^{-2}, 219.39 m^3 km^{-2} $year^{-1}$. The value of 219.39 m^3 km^{-2} $year^{-1}$ indicates, according to Gavrilovic, that the river basin is a region of very weak erosion.

CONCLUSIONS

The important results of this study are the determination of erosion processes, and new particular information about the recent state of the runoff and sediment yield in formats that can facilitate its efficient management and protection in the studied Region, illustrating the possibility of modelling of soil erosion with such approach.

The use of computer-graphic methods allowed the quantification of the environmental effects of soil erosion. Maximal outflow (incidence of 100 years) from the studied watershed, Qmax, was predicted on 170.53 m^3/s. The value of the Z coefficient was calculated on 0.270 and according to the result the watershed belongs in the destruction category IV. The strength of the erosion process is weak, and mixed erosion dominates in the area that has been subject of research. The calculated soil losses were 8622.3 m^3 per year for the watershed, specific 219.39 m^3/km^2 per year.

This study confirmed the findings of Blinkov and Kostadinov (2010), Tazioli (2009) and Ristic *et al.* (2011), as well as Spalevic (2011), which leads to the conclusion that the IntErO model and Erosion Potential Method are useful tools for researchers in calculation of runoff and sediment yield at the level of the river basins in the regions of South East Europe, similar to the Polimlje basin.

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Velibor SPALEVIC, Dragan RADANOVIC, Morteza BEHZADFAR, Vojislav DJEKOVIC, Aleksandar ANDJELKOVIC, Nedjo MILOSEVIC

PRORAČUN NANOSA U SLIVU TREBAČKE RIJEKE, POLIMLJE, CRNA GORA

SAŽETAK

Erozija zemljišta je globalni ekološki problem koji uzrokuje degradaciju zemljišta, taloženje u vodotocima, ekološku degradaciju i zagađenje. Važno je razumjeti procese erozije zemljišta u riječnim slivovima, da bismo kategorizovali područja podložna eroziji, te pronaći potencijalne mjere koje bi ublažile ove posledice na životnu sredinu. Cilj ovog istraživanja bio je proučiti procese erozije zemljišta u riječnom slivu, tako da bi potom mogli primijeniti efikasne mjere zaštite u proučavanom području. Ekološke činioce, koji su polaz za proračun intenziteta erozije zemljišta, uključili smo u IntErO simulacioni model. Primjena ove računarsko-grafičke metode omogućila je kvantificiranje učinaka erozije zemljišta na okoliš. Obrađeni su podaci koji se odnose na oticanje iz sliva iz Trebačke rijeke, kao i predikcija produkcije nanosa. Maksimalno oticanje iz sliva (za povratni period od 100 godina), Qmax, sračunato je na 170,53 m^3/s. Vrijednost koeficijenta Z sračunata je na 0,270, što proučavani sliv svrstava u IV kategoriju razornosti. Snaga erozionog proces je slaba; mješoviti erozija dominira u proučavanom području. Sračunati gubici zemljišta su 8622 m^3 godišnje iz sliva, specifično 219.39 m^3/km^2 godišnje. Ovo istraživanje potvrdilo je da su IntErO model i Metod potencijala erozije koristan alat istraživačima kod proračuna inteneziteta erozije i oticanja za slivove području Jugoistočne Evrope, slične Polimlju.

Ključne riječi: IntErO model, Metod potencijala erozije, erozija zemljišta, nanos, rečni slivovi, Polimlje