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CALCULATION OF SOIL EROSION INTENSITY AND MAXIMUM OUTFLOW FROM THE ROVACKI RIVER BASIN, MONTENEGRO

ABSTRACT

The Polimlje catchment area in the north of Montenegro covers an area of around 2200 km^2 where the river Lim receives 57 tributaries. One of the watersheds is the Rovacki River Basin, where the authors of this paper studied physical-geographical characteristics. Research of the Polimlje area was performed by several authors, applying classical qualitative and quantitative methods, using many mathematical models and various mechanical instruments in what was a very complex and time-consuming process. Many factors have influenced the development of erosion processes in the territory of the subject river basin. The most significant factors are the area's climate, relief, geological substrate and pedological composition, as well as the condition of the vegetation cover and the land use. The authors of this paper applied computer-graphic methods using "IntErO" software to calculate soil erosion intensity and maximum outflow. The research predicts that the maximal outflow (incidence for the next 100 years) from the river basin, Q_{max}, is 40 m^3s^{-1}. The river basin belongs in „Destruction Category IV", according to the classification system of Professor Gavrilovic. The strength of the erosion process is weak, and the type is mixed erosion. The real soil losses are 1371 m^3/year (117 m^3/km^2/year). To support faster vegetation recovery and protect the region from erosion processes, some biological protection measures need to be applied. These would prevent rapid runoff and maintain low transport of erosion material. This would further support reforestation and the recovery of grass, shrubs and trees.

Keywords: Montenegro, Polimlje, watershed, soil erosion, runoff, IntErO model

INTRODUCTION

The principal impediment to sustainability of agricultural production is land degradation. Among the various land degradation processes, soil erosion is the greatest threat to the conservation of soil and water resources. Studying soil

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erosion is important in order to estimate future soil productivity accurately. There is a fundamental concern to balance the use of natural resources against the need for the ecosystem protection from the field and regional scale to the national level (Bayramin et al. 2003, 2006). Erosion and torrential flows are very significant phenomena in Montenegro. The natural and agricultural ecosystems and local livelihoods are under increasing threat from several sources, including soil erosion and degradation of riverbeds causing an increased intensity and impact of flooding (Zingstra et al. 2012). There are major concerns in Southeast Europe about deforestation along and close to water courses and drinking water reservoirs, causing soil erosion, deposition of pollutants, clogging of water discharge channels, disturbances to agricultural production and decreases of the economic lifetime of hydropower plants.

Soil erosion is one of the greatest environmental problems faced by Southeast Europe. It is the most widely recognised and most common form of land degradation and a major cause of falling productivity (Stocking and Murnaghan 2001). These same problems are especially serious in Montenegro. According to Spalevic (2011), Kostadinov et al. (2006), Kadovic (1999) and Lazarevic (1996), water erosion has affected 13,135 km^2 or 95% of the total territory of Montenegro (13,812 km^2). The remaining area is characterised by alluvial accumulation. Erosion caused by water is dominant in terrain with steep slopes due to complex physical and geographical conditions paired with reckless logging (Spalevic et al. 2012).

The exploitation of forests and inappropriate use of land have caused a change to the structure of land use, and the condition of vegetation cover in the Rovacki River Basin. Soil and geological substrates are more exposed to impacts of various agents, particularly the impact of water, temperature and gravity.

The field survey showed that forests are degrading. In many locations, numerous ridges, gullies and ravines have appeared. These problems, observed during field surveys, prompted the authors to analyse soil erosion phenomena in this area using a computer-graphic method.

MATERIALS AND METHODS

Montenegro is located within two main river basins: the Black Sea and the Adriatic Sea. In general, both drainage basins are rich in water resources, even by world standards. In Montenegro, the area of the Black Sea drainage basin (to which the subject river basin belongs) is somewhat larger than the Montenegrin area of the Adriatic Sea drainage basin, covering about 7260 km^2, or about 52.5% of the country. The Ibar River drains to the West Morava River, while the Lim, Cehotina, Piva and Tara rivers drain to the Drina River.

The Lim is the most important Montenegrin river from a hydrographic perspective. Its major source is Plavsko Lake which is fed by Ljuca River with its major tributaries Vruja and Grncar.

The Lim River Basin is called Polimlje (coordinates: 43.245703 N, 19.580383 E (North); 42.508046 N, 19.905853 E (South); 43.148092 N, 19.485626 E (West); 42.963960 N, 20.120087 E (East). It consists of 57 river basins, of which ten are located in the Berane valley: 1) Navotinski Potok, 2) Vinicka, 3) Rovacki, 4) Krivaja, 5) Bistrica, 6) Kaludarska, 7) Makva, 8) Susica, 9) Dapsicka and 10) Crepulja (Lucka). This research focuses on the Rovacki Basin.

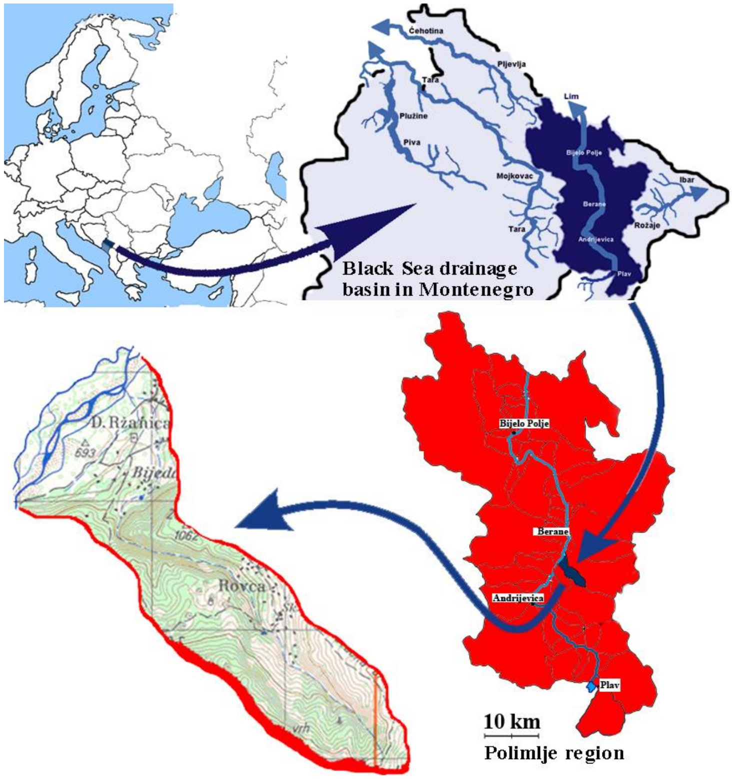

Figure 1. Study area [2]

The river that flows through the village of Rovca in Polimlje is called Rovacki Potok. It is a right-hand tributary of the River Lim and is located below the slopes of Zare, Ravne sume and Borje in the lower part of the river basin, and the village Rovca, surrounded by Rovacka brda and Crni vrh in the upper part of the basin. The highest elevations within the basin are found at the watershed boundary with the Sekularska Rijeka to the southeast.

The Rovacki River Basin encompasses an area of 11.7 km^2, and in terms of geomorphology, it is part of the natural entity of the Polimlje region of north-

[2] These drainage basin maps are for informational purposes only and do not constitute recognition of international boundaries or regions. The authors make no claims concerning the validity, accuracy or completeness of the maps nor assume any liability resulting from the use of the information therein.

eastern Montenegro. The natural length of the main watercourse, Lv, is 7.33 km. The shortest distance between the source and the mouth, Lm, is 6.07 km. The total length of the main watercourse, with tributaries of I and II class, ΣL, is 7.33 km.

Fieldwork was undertaken to collect detailed information on the intensity and forms of soil erosion, the status of the plant cover, the type of land use, and measures in place which contribute to reduction or alleviation of the erosion processes. Morphometric methods were used to determine the slope, specific lengths, expression and form of the slopes, the depth of the erosion base, the density of the erosion rills, the degree of the rills and other relevant parameters.

Figure 2. Lowlands close to the inflow of the Rovacki River into the Lim

Figure 3. Upper part of the Rovacki River Basin (Photos by Zoran Zecevic)

We drew on the earlier pedological work of the Agricultural Institute in Podgorica (today, the Biotechnical Faculty) led by Djuretic and Fustic, who analysed the physical and chemical properties of all Montenegrin soils from 1964 to 1988, including those in the study area of the Rovacki River Basin.

Furthermore, some pedological profiles had been reopened in the last five years, and soil samples were taken for physical and chemical analyses. The granulometric composition of the soil was determined using the pipette method; the samples were prepared using sodium pyrophosphate. The soil reaction (pH in H_2O and nKCl) was determined with a potentiometer. The total carbonates were determined by the volumetric Scheibler method; the content of the total humus was determined by the Kotzman method; easily accessible phosphorous and potassium were determined by the Al-method; and the adsorptive complex (y1, S, T, V) was determined by the Kappen method.

Estimating soil erosion and sediment yield requires comprehensive recognition of various factors, but identification of the parameters is difficult because of the complexity of soil erosion phenomena (Eisazadeh et al. 2012). There are a number of relevant empirical evaluation methods. These methods involve several steps: data acquisition, model specification and estimation (Gavrilovic, S., 1961, 1964, 1965, 1972, Madureiraa *et al.*, 2011).

Based on previous experience, the most reliable method for determining sediment yields and intensity of erosion processes for the subject area is the Erosion Potential Method (EPM). This method was created, developed, and calibrated in Yugoslavia (Gavrilovic, 1972). It is in use in Bosnia & Herzegovina, Croatia, Italy, Montenegro, Macedonia, Serbia and Slovenia. The EPM is distinguished by its high degree of reliability in calculating sediment yields as well as transport and reservoir sedimentation (Ristic, 2011).

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” was the most suitable on catchment level for the watershed management needs in this region.

Comparison between the Gavrilovic model and direct measurements of sediment transport was also carried out by Tazioli (2009). The study was applied to different types of basins in Italy and Africa. The numerical results obtained for some basins in the Marche region (Italy) are compared with empirical formula of EPM for the calculation of erosion. The researchers concluded that EPM is particularly useful for small and medium water courses (similar to those of the Apennine Ranges in Italy as well as the subject river basin), allowing an assessment of the erosion in the entire watershed.

Sediment yields were calculated with the EPM on 347,273 m^3/year for the 57 basins of Polimlje in Montenegro (Spalevic, 2011). The calculations correspond to the measured values obtained at the Potpec accumulation which is downstream from the study area. This correspondence suggests that results of the assessment of actual losses of soil erosion potential obtained by EPM are applicable to the study area.

The use of computer-graphics in research on runoff and the intensity of soil erosion have also been demonstrated in Montenegro, specifically in the Region of Polimlje (Spalevic et al., 2012, 2011, 2007, 2004, 2001, 2000, 2000a, 1999). We used the **Int**ensity of **Er**osion and **O**utflow (IntErO) program package (Spalevic, 2011) to obtain data on forecasts of maximum runoff from the basin and soil erosion intensity. IntErO - an integrated, second-generation version of the Surface and Distance Measuring (Spalevic, 1999) and River Basins program (Spalevic, 2000) - is characterized by simplicity of use in calculating a large number of input data. This simplicity makes it highly applicable for studying erosion process. EPM is embedded in the algorithm of this computer-graphic method.

RESULTS AND DISCUSSION

Physical-geographical characteristics and erosion factors

A number of authors have studied the physical-geographical characteristics of this area. Lutovac (1957) was among the first to call attention to the geographical individuality of the region where the Rovacki River Basin is located.

The area of the Rovacki River Basin is located from its inflow to the Lim (H_{min}, is 690 m) up to the watershed boundary with Sekularska Rijeka, where the H_{max} is 1567 m (Jankova glava).

In the area close to the inflow of the Rovacki River to the River Lim, there are moderate slopes around Ravne Sume and the village Donja Rzanica. The central part of the basin is characterised by a narrow valley that is 1900 m long, with an average width of about 320 m. This portion of the basin is located in the area between the village of Rovca and the village of Donja Rzanica. It is characterised by the steep slopes compared with the upper and lower parts of the basin. Regardless, erosion processes are not very intense in this part of the basin as there is a very good cover of forest vegetation. A Satellite image showing part of the Rovacki River Basin is presented in Figure 4.

Figure 4. Satellite image of the Rovacki River Basin (Google earth)

The watershed boundary with Sekularska River is mountainous terrain.

The average river basin decline, Isr, is 30%; the average river basin altitude, Hsr, is 1045.51 m; the average elevation difference of the river basin, D, is 355.51 m.

Climatic characteristics

Climate in the Rovacki River Basin is highly variable. It is characterised by short, mild, dry summers; rainy autumns and springs; and cold winters. The absolute maximum air temperature is $37.8^{O}C$. Winters are severe with temperatures falling to a minimum of $-28.3^{O}C$. There are two rainy seasons: the first is during the cold period (October–March) and the second during the warm period (April–September). The volume of torrential rain, h_b, is 71.9 mm. The average annual air temperature, t_0, is 9°C. The average annual precipitation, H_{god}, is 944 mm.

The geological structure of the area

In the structural-tectonic sense, the area belongs to the Durmitor geotectonic unit of the Inner Dinarides of northern and north-eastern Montenegro (Zivaljevic 1989, Bulajic 2001). The geological structure of the area 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 permeability for the region's bedrock, S_1, is 0.47. The structure of the Rovacki River Basin, according to bedrock permeability, is presented in Figure 5.

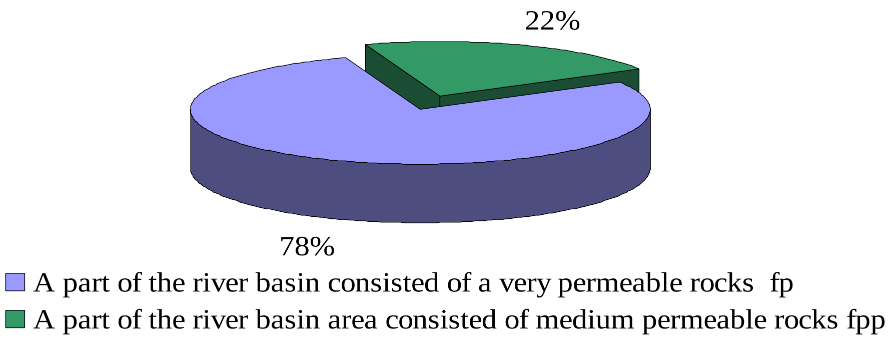

Figure 5. Structure of the Rovacki River Basin
according to the permeable products from rocks

Soil characteristics of the area

Soil properties always have an effect on the intensity of erosion, a fact that has been generally accepted and confirmed by various authors. Those studies paid particular attention to the types of soil and their properties, with particular focus on their propensity towards erosion.

From the inflow of the Rovacki River past the Lim to the surrounding mountainous terrain, the most common soil types are: alluvial-deluvial soils, 2.22 km^2; brown eutric soils, 1.64 km^2; brown district (acid) soils, 4.41 km^2 (on sandstone, granite, and gneiss – see the profile on Figure 7); brown soils on limestone, 2.68 km^2; and limestone and dolomite soils, 0.75 km^2.

Some smaller surfaces in the river basin, insignificant for the calculation of soil erosion intensity, are rankers and rendzina soils.

Figure 7. One of the Soil profiles (Brown eutric soil)

The structure of the Rovacki River Basin, according to the soil types, is presented in Figure 6.

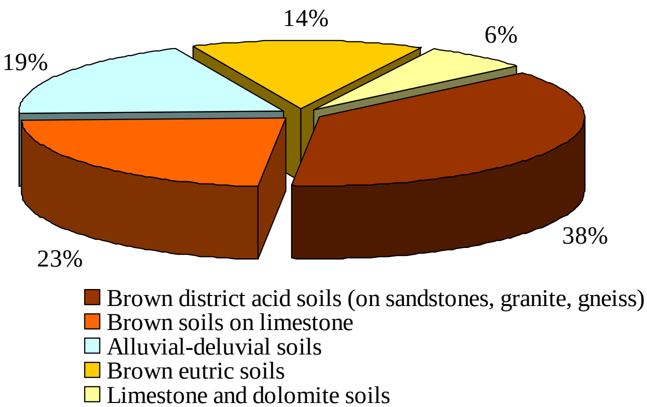

Figure 6. The structure of the Rovacki River Basin, according to the soil types

Vegetation

The control of soil erosion processes depends on appropriate land use and management planning (Dengiz and Akgul, 2005). One of the most important aspects of vegetation in relation to water resource management is its capability to reduce erosion. Through soil stabilisation, adequate vegetation cover minimises erosion and reduces water quality impairment caused by sedimentation. Forests protect storage capacities of water bodies and discharge capacities of watercourses by trapping sediments and pollutants from up-slope land use activities. In Europe, 96.3 million ha of forests are designated for protection of soil and water. This corresponds to 10% of the total forest area (Zingstra et al. 2012).

Water-induced soil erosion is the result of the complex effects of a large group of factors. In their research, Martinovic (1974), Ciric (1975), Lazarevic (1996), Curovic et al. (1999), Spalevic et al. (2000a), Fustic and Spalevic (2000), Spalevic et al. (2001) and Spalevic (2011) showed that erosion intensity is always influenced by soil properties and land use, the latter becoming increasingly important since the beginning of the anthropogenic period of the land's evolution. Over the last forty years, anthropogenic factors have significantly increased the pressure on agricultural and forest land, degrading vegetation cover and eventually resulting in serious degradation and loss of fertile soil.

For the purposes of calculating the maximum outflow from the Rovacki River Basin (Q_{max}), we analysed vegetative cover (ratio S2: portion of the basin covered by forest, grasses, and orchards, as well as barren land).

The subject area belongs to the Dinaridi Province of the Middle-Southeast European mountainous biogeographical region. The dominant vegetation consists of forests, which account for more than two thirds (57%) of the total vegetation cover.

Plant communities of the subject area belong to the following vegetation classes:

1. *Querco-fagetea* Br.-Bl. Et Vlieger 37.
2. *Quercetea robori-petreae* br.-Bl. Et Tx. 43.
3. *Erico-pinetea* Horvat 59.
4. *Vaccinio-picetea* Br.-Bl. 39.
5. *Betulo-adenostiletea* Br.-Bl. 48.
6. *Epilobietea angustifolii* Tx. Et Prsc. 50.
7. *Salicetalia purpureae* Moor 58.
8. *Alnetea glutinosae* Br.-Bl. et Tx. 43.
9. *Arhenanteretea* Br.-Bl. 47.
10. *Festuco brometea* Br.-Bl. et Tx. 43.
11. *Plantaginetea majoris* Tx. et Prsg. 50.
12. *Secalinetea* Br.-Bl. 51.
13. *Caricetea curvulae* Br.-Bl. 48.
14. *Elyno-seslerietea* Br.-Bl. 48.
15. *Salicetea herbacea* Br.-Bl. 47.
16. *Thlaspetea rotundifolii* Br.-Bl. 47.
17. *Asplenietea rupestris* Br.-Bl. 34.
18. *Phragmitetea* Tx. et Prsg. 49.
19. *Montio-cardaminetea* Br.-Bl. et Tx. 43.

On the vertical profile, the subject basin includes the following forest communities:

1. *Quercetum petraeae-cerridis,* Lak. Mostly on southern exposures of valleys along the main watercourse, and the lower parts of its tributaries.
2. *Quercetum petraeae montenegrinum,* Lak. On hilly portions of the river basin.
3. *Fagetum montanum.* Differentiated into several associations of which the most characteristic is Luzulo – *Fagion moesiacae*.
4. *Abieti - Fagetum moesiacae,* Blec and Lak.
5. *Picetum excelsae montanum.*
6. *Fagetum subalpinum,* above 1500 m including all exposures and various geological substrates.
7. *Picetum excelsae subalpinum,* above 1600 m.

Most of the river basin is covered by low beech forests (*Fagetum montanum).* 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 (Curovic et al. 2011), as well as those of subalpine forests of spruce with junipers.

According to our analysis, the coefficient f_s, (portion of the river basin under forest cover) is 0.57; f_t (grass, meadows, pastures and orchards) is 0.36 and f_g (bare land, ploughed land and ground without grass vegetation) is 0.07.

The coefficient of the river basin planning, X_a, is 0.46. Of the total river basin area, related to the river basin structure, degraded forests are the most widespread form (34.18%). The proportion is as follows: well-constituted forests (22.79%), meadows (19.22%), mountain pastures (13.62%), ploughed lands (6.86%), and orchards (3.34%). The coefficient of the vegetation cover, S_2, is 0.7. A summary of land use in the Rovacki River Basin is presented in Figure 8.

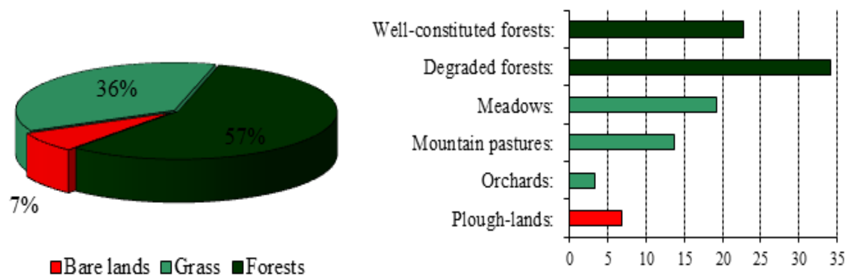

Figure 8. Land use in the Rovacki River Basin

Characteristics of the basin regarding issues of soil erosion and runoff

Erosion and torrential flows are pressing phenomena in Montenegro. Depending on geology and morphology, there are specific aspects of erosion. Inclination is a decisive factor in the development of erosion processes. Combined with improper land use, erosion processes have intensified. This is occurring especially in areas close to regional centres that have always been more densely populated, and the land more intensively used. This intensive use has provided the basis for classifying specific forms of erosion in the subject basin.

Terrain relief of the basin is characterised by a high percentage of steep slopes in the central and upper part of the basin from which water rapidly runs off. This situation is favourable for triggering soil erosion. Sheet erosion dominates in this area, but more severe forms such as rills, gullies and ravines, are also common.

Erosion affects some areas of agricultural and forest land around the village Rovca, but it mostly occurs close to roads that connect areas for forest exploitation and small rural communities with the village of Rovca. This erosion causes some site to lose fertile soils, and results in sterile alluvial deposits over fertile soils of the alluvial terraces close to the main watercourse downstream. It has also resulted in torrents, which have flooded roads and interrupted travel in the lower part of the basin.

We used IntErO software to process the input data required for calculation of the soil erosion intensity and the maximum outflow. The IntErO report for the studied basin is presented in Table 1.

Table 1. The IntErO report for the Rovacki River Basin

Inputs:			
River basin area	F	11.7	km²
The length of the watershed	O	17.97	km
Natural length of the main watercourse	Lv	7.33	km²
The shortest distance between the source and mouth	Lm	6.07	km
The total length of the main watercourse with tributaries	ΣL	7.33	km
River basin length measured by a series of parallel lines	Lb	8.96	km
The area of the larger portion of the river basin	Fv	7.77	km²
The area of the smaller portion of the river basin	Fm	3.93	km²
Altitude of the first contour line	h0	700	m
The lowest river basin elevation	Hmin	690	m
The highest river basin elevation	Hmax	1567	m
Portion of the basin consisting of a highly permeable rocks	fp	0.78	
Portion of the river basin with moderately permeable rocks	fpp	0.22	
Portion of the river basin with low permeability rocks	fo	0.00	
Portion of the river basin under forests	fs	0.57	
Portion of the river basin under grass, and orchards	ft	0.36	
Portion of the river basin consisting of bare land	fg	0.07	
Volume of the torrent rain	hb	71.9	mm
Incidence	Up	100	years
Average annual air temperature	t0	9	°C
Average annual precipitation	Hgod	944.3	mm
Types of soil products and related types	Y	0.7	
Coefficient of the river basin planning	Xa	0.46	
Numeral equivalents of clearly exposed erosion process	φ	0.25	

Results:

Coefficient of the river basin form	A	0.47	
Coefficient of the watershed development	m	0.61	
Average river basin width	B	1.31	km
(A)symmetry of the river basin	a	0.67	
Density of the river network of the basin	G	0.63	
Coefficient of the river basin tortuousness	K	1.22	
Average river basin altitude	Hsr	1045.51	m
Average elevation differences within the river basin	D	355.51	m
Average river basin decline	Isr	29.66	%
The height of the local erosion base of the river basin	Hleb	877	m
Coefficient of the erosion energy of the river basin's relief	Er	150.94	
Coefficient of the region's permeability	S1	0.47	
Coefficient of the vegetation cover	S2	0.7	
Energetic potential of water flow during torrent rains	2gDF^½	285.67	m km s
Temperature coefficient of the region	T	1	
Coefficient of the river basin erosion	Z	0.265	
Production of eroded material in the river basin	Wgod	4728.8	m^3/god
Coefficient of deposit retention	Ru	0.292	
Real soil losses	Ggod	1371.15	m^3/god
Real soil losses per km^2	Ggod/km^2	117.19	m^3/km^2 god

CONCLUSION

Many factors have influenced the development of erosion processes in the Rovacki River Basin. The most significant factors are the area’s climate, relief, geological substrate and pedological composition, as well as the condition of the vegetation cover and the land use.

(A)symmetry coefficient (0.67) indicates that there is a possibility of large flood waves in the river basin. The value of the G coefficient, which is 0.63, indicates a medium density hydrographical network. Maximum outflow (100 year event) from the river basin, Q_{max}, is calculated at 40 m^3 s^{-1}.

The value of the Z coefficient was 0.265. According to this result, the river basin belongs in the „Destruction Category IV”, according to the classification system of Professor Gavrilovic. The strength of the erosion process is weak, and the type is mixed erosion. The real soil losses are 1371 m^3/year (117 m^3/km^2/year).

There is a need to undertake preventative works in relation to flood control and measures against the possibility of increasing soil erosion processes. To support more rapid recovery of vegetation and slow down the erosion processes, some biological protection measures need to be applied, together with technical ones – notably the use of shoulders and ditches to partition water fluxes at the land surface in the central and upper parts of the river basin. These would mitigate rapid runoff and unwanted transport of eroded materials. These measures would be further supported by better land use, including afforestation, reforestation and the renewal of grasses, shrubs and trees.

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OBRAČUN INTENZITETA EROZIJE ZEMLJIŠTA I MAKSIMALNO OTICANJE IZ SLIVA ROVAČKI POTOK, CRNA GORA

SAŽETAK

Slivno područje Polimlja na sjeveru Crne Gore obuhvata površinu od oko 2200 km^2, gdje rijeka Lim prima 57 pritoka. Jedan od slivova je i Rovački potok, gdje su autori ovog rada proučavali fizičko-geografske karakteristike. Istraživanje Polimlja je vršeno od strane više autora, primjenom klasičnih kvalitativnih i kvantitativnih metoda, kao i korišćenjem matematičkih modela, što je pokazalo da je ovo veoma složen i dugotrajan proces. Mnogi faktori su uticali na razvoj erozionih procesa na teritoriji proučavanog sliva. Najznačajniji faktori su klima, reljef, geološka podloga i pedološki sastav, kao i stanje vegetacionog pokrivača i način korišćenja zemljišta. Autori ovog rada primijenili su kompjutersko-grafički model "IntErO" za obračun intenziteta erozije zemljišta i maksimalno oticanje iz sliva. Proračun maksimalnog oticanja (za povratni period od 100 godina) iz sliva, Qmax, je 40 m^3s^{-1}. Proučavani sliv spada u IV kategoriju razornosti prema klasifikaciji profesora Gavrilovića. Snaga erozionog procesa je kategorisana kao slaba, a po tipu u pitanju je mješovita erozija. Stvarni gubici zemljišta su 1371 m^3/god, ili po kvadratnom kilometru godišnje, 117 m^3/km^2/god.

Ključne riječi: Crna Gora, Polimlje, sliv, erozija zemljišta, oticanje, IntErO model