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PREDICTION OF THE SOIL EROSION INTENSITY FROM THE RIVER BASIN NAVOTINSKI, POLIMLJE (NORTHEAST MONTENEGRO)

SUMMARY

Soil erosion is acknowledged as a major environmental problem, threatening sustainable livelihoods around the world. Inappropriate land use and land management is often viewed as main cause of accelerated erosion rates. Therefore, prediction of soil erosion rates is important for prevention of its impact on the environment. For the River Basin Navotinski (Polimlje, Montenegro), we studied soil erosion processes, analyzing data on climate, relief, geological substrate and pedological composition, as well as the condition of the vegetation cover and the land use. The computer-graphic IntErO model was used to calculate soil erosion intensity and maximum outflow from the catchment area. The analyses indicated that there is a possibility for large flood waves to appear in the river basin Navotinski. The value of the Z coefficient is 0.120. The real soil loss value of 37 m^3/km^2/year indicates that the river basin belongs to the category V destruction class. The strength of the erosion process is low. The findings indicate that it is a region of very week erosion.

Keywords: Montenegro, Polimlje, Watershed, Soil erosion, runoff, IntErO model, land use.

INTRODUCTION

Soil erosion is one of the biggest environmental problems the world faces. It is a critical threat to food security and to the environment (Ebrahimpour *et al.* 2011). In Montenegro, water erosion is the most important erosion type. Water erosion is caused due to precipitation and consecutive runoff primarily, but also by fluvial erosion in water streams (Kostadinov *et al*. 2006). According to Kadović (1999) and Lazarević (1996), water erosion has affected 13,135 km^2 or 95% of the total territory of Montenegro (13,812 km^2). Alluvial accumulation characterises the remaining area. Erosion caused by water is dominant in terrain with high slopes due to complex physical and geographical conditions paired with reckless logging (Spalević, 2013).

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Reduction of soil erosion to preserve soil quality and to maintain land productivity constitutes 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. Field measurements of erosion and sedimentation using classical techniques are time-consuming and expensive (Bujan *et al*. 2000, Albaradeyia *et al*. 2010, Spalević, 2011). 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). Several software have been developed to predict the soil erosion. The authors of this study used the computer-graphic IntErO model for prediction of soil erosion intensity and maximum outflow from the catchment area.

MATERIAL AND METHODS

The river that flows through the village Navotina is called Navotinska River and its basin in the upper part is named Potoci (the Streams). The river is named after the Marsenica Rijeka hamlet, the village Navotina, it flows through (Vešović, 1935). It is a right-hand tributary of the river Lim and is placed on the slopes of Borje (1280 m) and Lekino hill, which is the watershed with the Šekularska River on the south (Spalević, 2011).

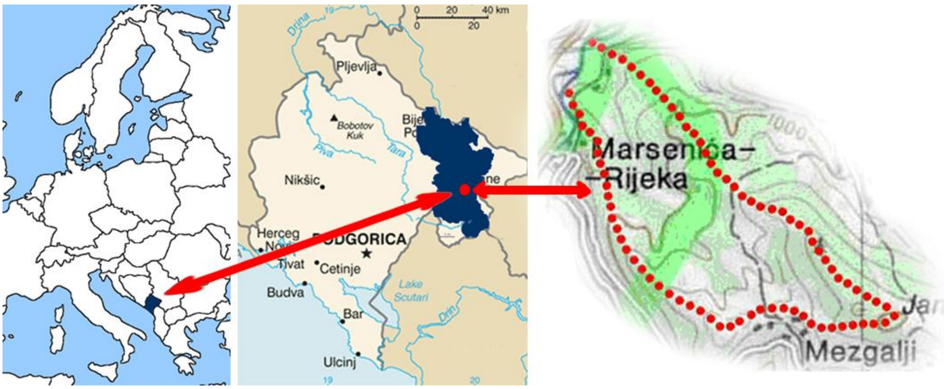

Figure 1. Study area

Figure 2. Inflow of the Navotinski river to Lim

Figure 3. Upper part of the River basin Navotinski

The River basin Navotinski encompasses an area of 8.4 km^2, and in terms of geomorphology and climate, it is part of the natural entity of the Polimlje region (North-East of Montenegro).

The natural length of the main watercourse, Lv, is 4.7 km. The shortest distance between the fountainhead and the mouth, Lm, is 4.29 km. The total length of the main watercourse, with tributaries of I and II class, ΣL, is 5.35 km.

Fieldwork was undertaken to collect detailed information on the intensity and the forms of the soil erosion, the status of the plant cover, the type of land use, and the measures in place contributing to the reduction or alleviation of 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, the density of the erosion rills and the degree of the rills.

We drew on the earlier pedological work of Fuštić and Djuretić (2000), who analysed the physical and chemical properties of all the Montenegrin soils, including those in the study area of the River basin Navotinski.

Furthermore, some pedological profiles had been reopened, and soil samples were taken for physical and chemical analysis. The granulometric composition of the soil was determined by 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.

Spatial modelling has emerged as an important tool in soil erosion studies and especially at the watershed scale (Memarian *et al.* 2012). The use of computer-graphics in research on runoff and the intensity of soil erosion have been demonstrated also in Montenegro, specifically in the Region of Polimlje (Spalević *et al.* 2013, 2012, 2007, 2004, 2003, 2001, 2000, 2000a, 1999, 1999a), and that approach was used in the research on the River basin Navotinski.

There are a number of empirical evaluation methods that may contribute to such an assessment. These methods involve several steps: data acquisition, model specification and estimation (Gavrilović, S., 1960, 1961, 1964, 1965, 1972, Madureiraa *et al.* 2011). We used the program Intensity of Erosion and Outflow - IntErO (Spalević, 2011) for forecasting of maximum runoff from the basin and the intensity of the soil erosion. Erosion Potential Method - EPM (Gavrilović, 1972) is embedded in the algorithm of this computer-graphic model.

RESULTS AND DISCUSSION

Physical-geographical characteristics and erosion factors

The area of the River basin Navotinski is located from its inflow to Lim (H_{min}, is 698 m) to the tops of Borje in the Southeast, where the H_{max} is 1280 m, which is the watershed with the Šekularska river.

Upper part of the river basin is hilly, mountainous terrain, with very steep slopes surrounded by the mountains. On the area close to the inflow of the Navotinski River to the river Lim there are mild slopes around the village Navotina.

The average river basin decline, Isr, is 22.26%; the average river basin altitude, Hsr, is 1032.69 m; the average elevation difference of the river basin, D, is 334.69 m. The area is full of very pronounced relief dynamics at the water-source zones, on that part of the basin called Potoci (the Streams).

Climatic characteristics

There is a highly variable climate and human pressure on the land in the River basin Navotinski. It is characterised by short, fresh, dry summers; rainy autumns and springs, and cold winters. The absolute maximum air temperature is 37.8^{O}C. Winters are tough, so much so that negative temperatures can fall to a minimum of -28.3^{O}C.

In terms of rainfall, there are two characteristically rainy times of the year: the first-cold period (October-March) and the second-warm period (April-September).

Basic data on the area needed for the calculation of soil erosion, intensity, and runoff are presented in Tables l - 5.

Table 1: Monthly precipitation sums in lit/m^2 – Berane, Montenegro

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	187.8	179.0	226.0	193.0	298.0	211.0	179.0	158.1	219.0	254.0	370.6	222.0
Av	82.7	73.5	61.9	74.6	82.2	72.0	58.3	56.1	72.5	93.0	118.3	99.2
St.d.	53.0	45.7	38.1	43.5	47.2	44.6	42.0	37.5	53.2	61.1	68.8	55.3

Year = 944.3

Table 2: Daily Maximum in lit/m^2 - Berane, Montenegro

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	54.0	87.0	61.3	77.4	80.5	47.5	43.0	65.4	115.0	96.0	73.4	62.6
Av	25.5	23.0	21.1	23.8	22.4	19.6	17.6	20.3	28.5	30.0	29.7	25.9
St.d.	15.9	15.3	12.2	16.2	13.5	10.1	9.0	13.8	18.7	18.8	15.7	14.6

Table 3: Monthly average air temperature in ^{O}C - Berane, Montenegro

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
max	6.5	6.9	10.0	18.8	18.8	23.6	25.0	26.5	21.2	17.0	13.2	9.4
min	-6.5	-6.6	-0.7	0.6	9.8	8.3	16.2	14.2	10.0	5.4	-1.0	-4.6
Av	-1.5	0.6	4.5	8.8	13.6	16.5	18.7	18.2	14.4	9.5	4.6	0.2
St.d.	2.6	3.0	2.4	2.7	1.7	2.0	1.6	1.9	2.0	2.0	2.6	2.7

Table 4: Absolute maximum of air temperature in ^{O}C - Berane, Montenegro

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
max	17.7	21.0	26.5	27.5	32.8	34.3	37.8	37.0	34.4	30.0	23.9	20.2
Av	12.3	15.0	19.7	23.2	27.7	30.0	32.6	32.7	28.9	25.2	18.5	13.5
St.d.	3.1	3.2	3.5	2.4	2.6	2.5	2.9	2.3	2.5	2.3	3.5	3.2

Table 5: Absolute minimum of air temperature in ^{O}C - Berane, Montenegro

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
min	-28.3	-24.8	-19.0	-7.9	-4.2	0.2	1.9	2.2	-6.1	-7.7	-19.8	-24.1
Av	-15.9	-13.3	-8.1	-2.7	1.2	4.0	6.3	5.8	2.0	-3.1	-7.5	-12.4
St.d.	5.6	4.5	4.7	2.9	2.3	2.2	2.5	2.0	2.9	3.0	4.5	6.2

The volume 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

The area belongs to the East Bosnian-Durmitor block of Northern and North-eastern Montenegro, representing different nappes-thrust sheets (Dimitrijević, 1992). These nappes consist of Late Palaeozoic and Lower Triassic clayey-marly-sandy beds, Middle Triassic eruptive rocks and Middle and Upper Jurassic diabase-chert formation rocks (Radulovic and Radulovic, 1997).

The structure of the River basin Navotinski, according to the permeable products from rocks is presented in the Figure 4. The coefficient of the region's permeability, S_1, is calculated on 0.58.

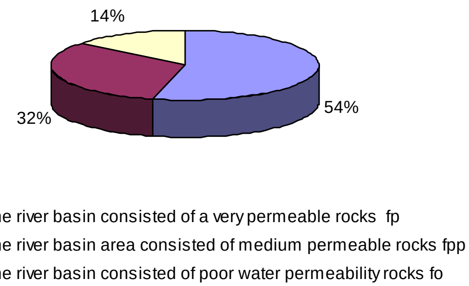

Figure 4. Structure of the River basin Navotinski according to the permeable products from rocks

Soil characteristics of the area

The fact that soil properties always have an effect on the intensity of erosion has been generally accepted and confirmed in the work of Baver (1959) among others. Those studies paid particular attention to the types of soil and their properties, with particular focus on their propensity towards erosion.

Going from the inflow of the Navotinski River past Lim to the surrounding mountainous terrain, the most common soil types are: Alluvial-deluvial soils, 0.5 km^2; Brown eutric soils, 0.67 km^2; Brown district (acid) soils, 1.43 km^2 (on sandstones, granite, gneiss - see the profile on Figure 6); Brown soil on limestone, 2.27 km^2; Limestone and dolomite soils, 3.53 km^2. In some smaller areas in the river basin there are also soils such as rankers (resting on bedrock within 30 cm depth) and rendzina (shallow soils with solid or fragmented calcareous rock at depth, in certain topographic positions with a brightly coloured subsoil or mixed AB horizon, distinctive vegetation cover).

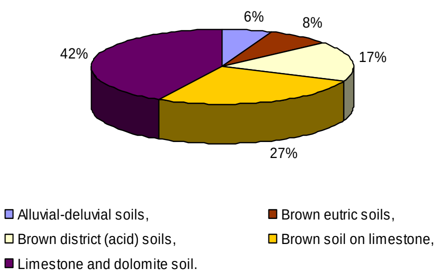

Figure 5. The structure of the Navotinski River Basin, according to the soil types

Figure 6: One of the Soil profiles (Brown district soils)

Vegetation

In Southern Alps, gully erosion has led to the formation of extensive degraded areas called badlands (Poesen *et al*. 2003), in which high rates of soil loss have been observed (Mathys *et al*. 2003). Therefore, these eroded lands, which are now subjected to rigorous management, often need ecological restoration (Rey, 2009). In recent years, ecological engineering solutions have developed and promote the use of vegetation to protect soils and prevent water erosion (Norris *et al*. 2008). Plant species can have a major effect on erosion dynamics and soil losses by retaining sediment transported during concentrated runoff (Burylo *et al*. 2012).

For the purposes of calculating the maximum outflow from the River basin Navotinski (Qmax) we analysed a vegetative cover (ratio S2: part of the basin covered by forest, the grasses, orchards, as well as the barren land).

In biogeographic terms, the studied area belongs to the Dinaridi Province of the Middle-Southern-East European mountainous biogeographical region. The dominant type of vegetation consists of forests which account for more than two thirds (68%) of the total vegetation cover.

Plant communities of the studied area belong to the following classes of vegetation: *Querco-fagetea* Br.-Bl. Et Vlieger 37.; *Quercetea robori-petreae* br.-Bl. Et Tx. 43.; *Erico–pinetea* Horvat 59.; *Vaccinio-picetea* Br.-Bl. 39.; *Betulo-adenostiletea* Br.-Bl. 48.; *Epilobietea angustifolii* Tx. Et Prsc. 50.; *Salicetalia purpureae* Moor 58.; *Alnetea glutinosae* Br.-Bl. et Tx. 43.; *Arhenanteretea* Br.-Bl. 47.; *Festuco brometea* Br.-Bl. et Tx. 43.; *Plantaginetea majoris* Tx. et Prsg. 50.; *Secalinetea* Br.-Bl. 51.; *Caricetea curvulae* Br.-Bl. 48.; *Elyno-seslerietea* Br.-Bl. 48.; *Salicetea herbacea* Br.-Bl. 47.; *Thlaspetea rotundifolii* Br.-Bl. 47.; *Asplenietea rupestris* Br.-Bl. 34.; *Phragmitetea* Tx. et Prsg. 49.; *Montio-cardaminetea* Br.-Bl. et Tx. 43.

On the vertical profile, River basin Navotinski is differentiated from the following forest communities: (1) *Quercetum petraeae-cerridis*, Lak. Mostly in the southern exposure of the valleys on the main watercourse, and the lower parts of its tributaries; (2) *Quercetum petraeae montenegrinum,* Lak. On the hilly parts of the river basin; (3) *Fagetum montanum.* Differentiated into several associations of which the most characteristic is Luzulo - *Fagion moesiacae*; (4) *Abieti - Fagetum moesiacae* Bleč and Lak.; (5) *Picetum excelsae montanum*.

Most of the river basin is covered by low beech forests *(Fagetum montanum).* Beech forests are characterized by dense canopy. Beech as a species tolerates shade well, particularly in youth; its growth and increment depend very much on the quantity of light. Absence of light can slow down beech growth significantly (Čurović and Spalević, 2005). On the southern exposures there are forests of 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).* At the higher parts of the basin there are subalpine forests of beech (Čurović *et al*. 2011).

In the highest altitudes of the studied River basin, close to the watershed with the Šekularska River basin is mixed of broadleaves and deciduous tree species (*Abieti - Fagetum moesiacae)* and forest of fir and spruces *(Picetum excelsae montanum)*. Going downstream, the area is covered with hygrophilic forest (*Alnetea glutinosae, Salicetea herbacea).*

In last decades climate change on forest ecosystems affected moving of the vegetation vertical layout belts (Čurović and Spalević, 2010).

According to our analysis, the coefficient $f_{š}$, (part of the river basin under forests) is 0.68, f_t (grass, meadows, pastures and orchards) is 0.29 and f_g (bare land, plough-land and ground without grass vegetation) is 0.03.

The coefficient of the river basin planning, X_a, is 0.27. Of the total river basin area, related to the river basin structure, well-constituted forests are the most widespread form (57.36%). The proportion is as follows: meadows (13.72%), mountain pastures (13.08%), degraded forests (11.04%), plough-lands (2.75%), and orchards (2.05%).

The coefficient of the vegetation cover, S_2, is 0.67.

Characteristics of the basin regarding issues of soil erosion and runoff

Water-induced soil erosion is the result of the complex effect of a whole group of factors. In their research, Baver (1959), Lazarević (1996), Ćirić (1975), Čurović *et al*. (1999), Popović *et al.* (1999, 2000), Fuštić and Spalević (2000), Spalević *et al.* (2001), Spalević *et al.* (2008), Spalević (2011), Đeković *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. Over the last forty years, anthropogenic factors have significantly increased the pressure on agricultural and forest land, degrading the vegetation cover, which eventually results in serious degradation and loss of fertile soil.

The relief of the hilly-mountainous terrain is characterized by many steep slopes from which the water runs off and flows quickly, which is favourable for triggering the soil erosion process. The dominant erosion form in this area is surface runoff, but more severe forms of erosion, such as rills, gullies and ravines, occur also.

The erosion activities affect some areas of agricultural and forest land, but they are mostly close to roads that connect areas for forest exploitation and small rural communities with the village Navotina. The erosion causes some places to lose fertile land, and results in sterile alluvial deposits on the fertile soils of the small alluvial terraces close to the main watercourse. It has also resulted in torrents, which have flooded roads and interrupted travel and the exploitation of timbers.

We used the software IntErO to process the input data required for calculation of the soil erosion intensity and the maximum outflow. A complete report for the River basin Navotinski is presented in Table 6.

Table 6: Part of the IntErO report for the River basin Navotinski

INPUT DATA:			
River basin area	F	8.4	km²
The length of the watershed	O	14.4	km
Natural length of the main watercourse	Lv	4.7	km²
The shortest distance between the fountainhead and mouth	Lm	4.29	km
The total length of the main watercourse with tributaries	ΣL	5.35	km
The area of the bigger river basin part	Fv	5	km²
The area of the smaller river basin part	Fm	3.4	km²
The lowest river basin elevation	Hmin	698	m
The highest river basin elevation	Hmax	1280	m
A part of the river basin consisted of a very permeable rocks	fp	0.54	
A part of the river basin area consisted of medium permeable rocks	fpp	0.32	
A part of the river basin consisted of poor water permeability rocks	fo	0.14	
A part of the river basin under forests	fš	0.68	
A part of the river basin under grass, and orchards	ft	0.29	
A part of the river basin under bare land and without grass vegetation	fg	0.03	
The volume of the torrent rain	hb	71.9	mm
Average annual air temperature	t0	9	°C
Average annual precipitation	Hgod	944	mm
Types of soil products and related types	Y	0.7	
River basin planning, coefficient of the river basin planning	Xa	0.27	
Numeral equivalents of visible and clearly exposed erosion process	φ	0.21	
RESULTS:			
Coefficient of the river basin form	A	0.6	
Coefficient of the watershed development	m	0.46	
Average river basin width	B	1.45	km
(A)symmetry of the river basin	a	0.38	
Density of the river network of the basin	G	0.64	
Coefficient of the river basin tortuousness	K	1.09	
Average river basin altitude	Hsr	1032.69	m
Average elevation difference of the river basin	D	334.69	m
Average river basin decline	Isr	22.26	%
The height of the local erosion base of the river basin	Hleb	582	m
Coefficient of the erosion energy of the river basin's relief	Er	108.82	
Coefficient of the region's permeability	S1	0.58	
Coefficient of the vegetation cover	S2	0.67	
Energetic potential of water flow during torrent rains	2gDF^½	234.86	m km s
Coefficient of the river basin erosion	Z	0.120	
Production of erosion material in the river basin	Wgod	1039.88	m³/god
Coefficient of the deposit retention	Ru	0.299	
Real soil losses	Ggod	310.6	m³/god
Real soil losses per km²	Ggod/km²	36.98	m³/km² god

CONCLUSIONS

Our research pointed out the following:

Value of (a)symmetry coefficient of 0.39 indicates that there is a possibility of a large flood waves in the river basin.

The value of the G coefficient that was 0.64 indicates that there is a medium density of the hydrographical network. Maximal outflow (appearance of 100 years) from the river basin, Q_{max}, is calculated on 50 m^3s^{-1}.

The value of the Z coefficient was 0.120. According to the result of the value of Z the river basin belongs in the destruction category V. The strength of the erosion process is weak. Sheet erosion dominates in this area.

The real soil losses are 310 m^3/year (37 m^3/km^2/year).

It is recommended to undertake measures against the possibility of increasing soil erosion processes in some specific spots on the upper part of the river basin. 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.

The restoration and erosion control measures will decrease degradation processes and will help rehabilitation of the landscape.

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PRORAČUN INTENZITETA EROZIJE ZEMLJIŠTA IZ SLIVA NAVOTINSKOG POTOKA, POLIMLJE (SJEVEROISTOČNA CRNA GORA)

SAŽETAK

Erozija zemljišta je prepoznata kao veliki ekološki problem, prijeteći održivom životnom standardu širom svijeta. Neodgovorno korišćenje i upravljanje zemljištem je često glavni uzrok povećanju intenziteta erozije. Predviđanje stepena intenziteta erozije zemljišta je važno za sprečavanje njegovog uticaja na životnu sredinu. Za sliv Navotinski potok (Polimlje, Crna Gora) proučavali smo procese erozije zemljišta, analizirajući pri tom klimatske podatke, reljef, geološku podlogu i pedološki sastav, kao i stanje vegetacionog pokrivača i način korišćenja zemljišta. Kompjutersko-grafički model IntErO je korišćen za izračunavanje intenziteta erozije zemljišta i maksimalno oticanje iz sliva. Analize ukazuju na mogućnost pojave velikih poplavnih talasa u slivu Navotinskog potoka. Vrijednost koeficijenta Z je 0.120. Gubici zemljišta is sliva sračunati su na 37 m^3/km^2/godišnje, što ukazuje da rečni sliv pripada V kategoriji razornosti prema klasifikaciji profesora Gavrilovića. Snaga erozionog procesa kod pručavanog sliva kategorisana je kao slaba.

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