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CALCULATION OF RUNOFF AND SOIL EROSION ON THE TIFRAN WATERSHED, POLIMLJE, NORTH-EAST OF MONTENEGRO

SUMMARY

Soil erosion is a growing problem in South East Europe and is creating a hazard to soil quality, environment and biodiversity. It is well-known fact that runoff, soil erosion and as consequence sedimentation, are decreasing a reservoirs capacity and that is noticeable in the region of Polimlje, where the studied watershed belongs. This is causing the new expenses to the weak economies of the Countries of this underdeveloped area. Ecological factors, which are the basis for the calculation of soil erosion intensity, we included in the simulation model. At the level of the watershed, the use of computer-graphic methods allowed the quantification of the environmental effects of runoff and soil erosion. Maximal outflow (incidence of 100 years) from the studied watershed, Q_{max}, was predicted on 31 m^3/s. The value of the Z coefficient was calculated on 0.271 and according to the result the watershed belongs in the destruction category IV. The strength of the erosion process is low, and mixed erosion dominates in the studied area. The calculated soil losses were 277 m^3 per year for the watershed, specific 115.5 m^3/km^2 per year. We have not evaluated proposed anti-erosion measures in the area because they have not been put into practice. This study shown that IntErO model is a useful tool for researchers in calculation of runoff and sediment yield at the level of the river basins in the South East European region.

Key words: Runoff, soil erosion, sediment yield, watershed, Polimlje

INTRODUCTION

In Europe, soil erosion is caused mainly by water. Rill- and inter-rill erosion affects the largest area, whereas gully erosion and landslides are relatively localised though often visually striking. Soil losses due to water erosion are high in southern Europe (Van Lynden, 1995). In Europe, excluding Russia, is roughly estimated to be 114 million hectares (17% of total land area), of which 80% is topsoil loss and 20% terrain deformation (Gobin *et al.*, 2004).

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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 as well as ecological impacts (Vanmaercke *et al*, 2011).

This was the reason why the authors of this study approach this problem on catchment scale.

This requires the collection of field data, various measurements, as well as 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 is time-consuming and expensive (Bujan et al. 2000). 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).

This was the reason why the authors of this study analyse this problem using computer-graphic methods, illustrating the possibility of modelling of sediment yield and runoff with such approach.

MATERIAL AND METHODS

We studied the area of the Tifran watershed that encompasses an area of 2.4 km^2, with the length of the watershed of 7.63 km. It is a part of the natural entity of the Polimlje region (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)).

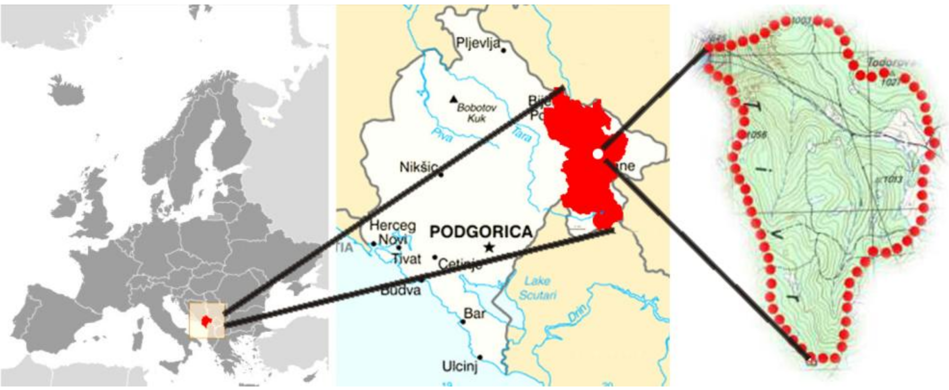

Figure 1: Study area

Figure 2: Polica & Tifran canyon (*Photo: Velibor Spalevic and Marijan Marijanovic*)

The natural length of the main watercourse, Lv, is 2.3 km. The shortest distance between the fountainhead and the mouth, Lm, is 1.82 km. The total length of the main watercourse, with tributaries of I and II class, ΣL, is 4.58 km.

Fieldwork was undertaken to collect detailed information on the intensity and forms of soil erosion, the status of plant cover, the type of land use. Morphometric methods were used to determine the slope, the specific lengths, the form of the slopes and the depth of the erosion base. We have not evaluated proposed anti-erosion measures in the area because they have not been put into practice.

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 H_2O 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 (Jakovljević *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).

Understanding of soil erosion processes is essential in appreciating the extent and causes of soil erosion and in planning soil conservation. Spatial modelling has emerged as an important tool in soil erosion studies, 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 also been demonstrated in Montenegro, specifically in the Region of Polimlje (Spalevic *et al*. 2013, 2013a, 2013b, 2013c, 2013d, 2012, 2008, 2007, 2004, 2003, 2001, 2000, 2000a, 1999, 1999a), Fustic and Spalevic (2000). That approach was used in the research on the studied watershed of Tifran.

There are a number of relevant empirical evaluation methods for calculation of runoff and soil erosion intensity. These methods involve several steps: data acquisition, model specification and estimation (Madureiraa *et al.* 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 (EPM) was, according to them, the most suitable on catchment level for the watershed management needs in this Region.

Tazioli (2009) undertook a comparison between the Erosion potential method (EPM) of Gavrilovic model (1972) and direct measurements of sediment transport. The study was applied to different equipped basins in Italy and Africa. The numerical results obtained for some basins in the Marche region (Italy) were compared with the empirical formula of EPM for the calculation of erosion. Tazioli’s research concluded that EPM is particularly useful for small and medium water courses (similar to those of the Apennine ranges in Italy, but also for the Polimlje region and the studied watershed), allowing for an assessment of erosion in the whole watershed.

This methodology is in use also 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 *et al.*, 2011).

We used the Intensity of Erosion and Outflow (IntErO) programme package (Spalevic 2011) to obtain data on forecasts of maximum runoff from the basin and soil erosion intensity. EPM is embedded in the algorithm of this computer-graphic method.

RESULTS AND DISCUSSION

Physical-Geographical Characteristics

The Tifran watershed stretches from its inflow to Lim (H_{min}, is 653 m a.s.l.) to the top of the Todorovac (1027 m a.s.l.) on the North and the Tifran Canyon in the South West, where the H_{max} is 1123 m.

There are mild slopes around the villages Babino and Masnica and very steep slopes in the North West, where the watercourse is cutting the Canyon flowing downstream to the river Lim. The relief has very pronounced dynamics. The average river basin decline, Isr, is 29.58%; the average river basin altitude, Hsr, is 1031.69 m; the average elevation difference of the river basin, D, is 378.69 m.

Climatic Characteristics

The climate in the studied watershed is very variable. The absolute maximum air temperature is 37.8^{O}C. Winters are severe, so much so that negative temperatures can fall to a minimum of -28.3 ^{O}C. There are two typical rainy periods of the year: the first, October-March and the second, April-September. The amount of torrential rain, h_b, is 71.9 mm. The average annual air temperature, t_0, is 9 °C. The average annual precipitation, H_{year}, is 944 mm.

The Geological Structure and Soil Characteristics 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). The coefficient of the region's permeability, S_1, is 0.53. The composition of the geological substrate and the soil formed on this substrate are, for the most part, resistant to erosion where the area is well protected by adequate vegetation cover.

The structure of the studied watershed according to the permeable products from rocks is presented in Figure 3.

Several researchers (Pavicevic, 1956, 1957; Pavicevic and Tancic 1970, Fustic and Djuretic, 2000; Spalevic 1999; Spalevic, 2011) studied the soils of the high mountains in Upper Polimlje, including the area of this watershed. The most common soil types for the studied watershed were alluvial-deluvial soils (11.18% of the studied area), brown eutric soils (3.89%), and brown district (acid) soils (84.93%).

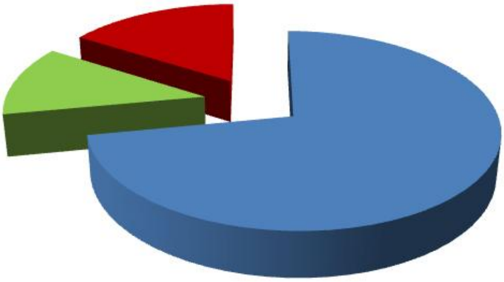

Figure 3: Structure of the studied watershed according to the permeable products from rocks

Figure 4. Tifran, Alluvial terrace (653 m a.s.l.) close to the inflow of the studied watercourse in the river Lim, downstream Berane

Figure 5. One of the soil profiles opened in the studied area

Vegetation

For the purposes of calculating the maximum outflow from the Tifran watershed (Q_{max}), we analysed the vegetative cover (ratio S_2: part of the basin covered by forest, the grasses, orchards, as well as the barren land).

Plant communities of the studied area belongs to the following classes of vegetation: *Querco-fagetea* Br.-Bl. Et Vlieger 37.; *Quercetea robori-petreae* br.-Bl. Et Tx. 43.; *Alnetea glutinosae* Br.-Bl. et Tx. 43.; *Arhenanteretea* Br.-Bl. 47.; *Festuco brometea* Br.-Bl. et Tx. 43.; *Plantaginetea majoris* Tx. et Prsg. 50; *Salicetea herbacea* Br.-Bl. 47.; etc.

On the vertical profile, the Tifran watershed is differentiated from the following forest communities:

1.*Quercetum petraeae-cerridis*, Lak..
2.*Quercetum petraeae montenegrinum*, Lak.
3.*Fagetum montanum* - several associations (Curovic *et al*., 2011).

Most of the hilly part of the river basin is covered by forests of Sessile oak and Turkish oak (*Quercetum petraeae-cerridis*). Near the river in the lower part of the river basin is covered with hygrophilic forest (*Alnetea glutinosae*, *Salicetea herbacea*). Those forest communities are characterized by presence of numerous tree species. Beech forests are on the higher altitudes of the river basin and characterized by low share of high quality wood. In past decades climate change on forest ecosystems affected moving of the vegetation vertical layout belts (Curovic and Spalevic, 2010).

According to our analysis, the coefficient f_s, (part of the river basin under forests) is 0.6; f_t (grass, meadows, pastures and orchards) is 0.31 and f_g (bare land, plough-land and ground without grass vegetation) is 0.09.

The coefficient of the river basin planning, X_a, is 0.46. Of the total watershed, related to the land use structure degraded forest is the most widespread form (35.91%). The proportion is further as follows: well-constituted forests - 23.94%; meadows - 18.81%; mountain grasslands – 10.63%; plough-lands (arable land) – 9.34%, and orchards – 1.37%.

The coefficient of the vegetation cover, S_2, is 0.70.The structure of land use of the Tifran watershed is presented in Figure 6.

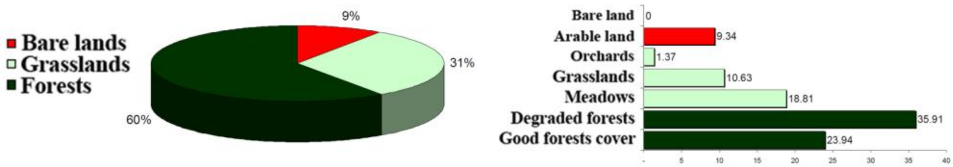

Figure 6: Land use structure in the Tifran watershed

Characteristics of the Watershed in relation to Soil Erosion and Runoff

Soil erosion represents key environmental issues worldwide (Stoffel and Huggel, 2012) and major initiator of land degradation (Verheijen *et al*., 2009). Recent studies dealing with soil conservation subjects have discussed and sometimes questioned, the magnitude of land degradation in the Region, human responses, and the linkages with land use and cover (LUC) changes where water is one of the causes of positive but also negative effects on the land and environment (Nyssen *et al*. 2012).

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 Tifran watershed is presented in Table 1.

Table 1. Part of the IntErO report for the Tifran watershed

INPUT DATA			
River basin area	F	2.4	km²
The area of the bigger river basin part	Fv	1.8	km²
The area of the smaller river basin part	Fm	0.6	km²
Natural length of the main watercourse	Lv	2.3	km
Shortest distance between fountain head and mouth	Lm	1.82	km
The length of the main watercourse with tributaries	ΣL	4.58	km
River basin length (series of parallel lines)	Lb	3	km
Altitude of the first contour line	h0	700	m
Equidistance	Δh	100	m
The lowest river basin elevation	Hmin	653	m
The highest river basin elevation	Hmax	1123	m
A part of the river basin with a very permeable rocks	fp	0.72	
Area consisted of medium permeable rocks	fpp	0.12	
Area with of poor water permeability rocks	fo	0.16	
A part of the river basin under forests	fs	0.60	
A part of the river basin under grass, and orchards	ft	0.31	
A part of the river basin without grass vegetation	fg	0.09	
The volume of the torrent rain	hb	71.9	mm
Incidence	Up	100	years
Average annual air temperature	t0	9	°C
Average annual precipitation	H_{year}	944	mm
Types of soil products and related types	Y	0.8	
Coefficient of river basin planning	Xa	0.46	
Numeral equivalents of visible erosion process	φ	0.22	

RESULTS:			
Coefficient of the river basin form	A	0.54	
Coefficient of the watershed development	m	0.42	
Average river basin width	B	0.8	km
(A)symmetry of the river basin	a	1	
Density of the river network of the basin	G	1.91	
Coefficient of the river basin tortuousness	K	1.27	
Average river basin altitude	Hsr	1031.69	m
Average elevation difference of the river basin	D	378.69	m
Average river basin decline	Isr	29.58	%
The height of the local erosion base of the river basin	Hleb	470	m
Coefficient of the erosion energy of the r. basin's relief	Er	120.2	
Coefficient of the region's permeability	S1	0.53	
Coefficient of the vegetation cover	S2	0.7	
Analytical presentation of the water retention in inflow	W	0.9321	m
Energetic potential of water flow during torrent rains	2gDF^½	133.54	m km s
Maximal outflow from the river basin	Q_{max}	31	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	W_{year}	1004.9	m³/year
Coefficient of the deposit retention	Ru	0.276	
Real soil losses	G_{year}	277.22	m³/year
Real soil losses per km²	G_{year/km^2}	115.51	m³/km² year

(A)symmetry coefficient indicates that there is a possibility of large flood waves to appear in the basin. The value of G coefficient indicates there is high density of the hydrographic network. Average river basin decline indicates that in the river basin prevail very steep slopes.

The value of the Z coefficient was calculated on 0.271 and according to the result the watershed belongs in the destruction category IV. The strength of the erosion process is low, and mixed erosion dominates in the studied area. The calculated soil losses were 277 m^3 per year for the watershed, specific 115.5 m^3/km^2 per year.

Sediment yields were calculated with the IntErO model on 347,273 m^3/year for all the 57 basins of Polimlje in Montenegro **(**Spalevic 2011), including 277 m^3/year for the study on the Tifran watershed. The calculations for the Polimlje region corresponded to the results obtained by the engineers Begic and Vranic ($0.35 \times 10^6 m^3$) for the Potpec accumulation, which is downstream from the study area. This correspondence suggests that the assessment results of actual losses of soil erosion potential obtained by IntErO model are eligible for the study area.

CONCLUSIONS

Many factors have impact on the erosion processes in the territory of the Tifran watershed. The most significant factors are climate, relief, geological substrate and pedological composition, as well as land use.

Maximal outflow (over 100 years) from the river basin, Q_{max}, was calculated on 31 m^3/s. The study shown that the strength of the erosion process is medium, and erosion type is mixed erosion. The calculated soil losses were 277 m^3 per year for the watershed, specific 115.5 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) what leads to the conclusion that the IntErO model may be a useful tool 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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PRORAČUN INTENZITETA EROZIJE I OTICAJA SA SLIVNOG PODRUČJA TIFRAN, POLIMLJE, SJEVEROISTOK CRNE GORE

SAŽETAK

Erozija je rastući problem u jugoistočnoj Evropi i predstavlja opasnost za kvalitet zemljišta, životnu sredinu i biodiverzitet. Dobro je poznata činjenica da oticanje (sa slivnih površina), erozija zemljišta, a kao krajnja posledica taloženje produkovanog nanosa, smanjuje kapacitet akumulacijama i rezervoarima. Ova činjenica nije zaobišla ni region Polimlja, gdje se nalazi proučavano područje. Ovo izaziva dodatne troškove za slabu privredu ovog nerazvijenog područja. Ekološki faktori, koji su osnova za izračunavanje intenziteta erozije zemljišta, su uključeni u simulacioni model. Na nivou sliva, upotreba kompjutersko-grafičkog metoda omogućila je kvantifikaciju ekoloških efekata oticanja i intenziteta erozije zemljišta. Maksimalni oticaj sa slivnog područja (povratni period od 100 godina), Q_{max}, sračunat je na 31 m^3/s . Vrijednost koeficijenta Z je izračunata na 0.271 i prema ovom rezultatu sliv je svrstan u IV kategoriju razornosti. Sračunati gubici zemljišta sa slivne površine su 277 m^3 godišnje, specifično 115,5 m^3/km^2 godišnje. Nismo ocjenjivali mjere protiverozione zaštite na proučavanom području, jer one nisu ni primjenjivane. Ova studija pokazala je da IntErO model koristan alat kod obračuna oticanja i istraživanja erozionih procesa na nivou sliva.

Ključne riječi: Oticaj, erozija zemljišta, nanos, sviv, Polimlje