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# CALCULATION OF SOIL EROSION INTENSITY AND RUNOFF OF THE LAPNJAK WATERSHED, POLIMLJE, MONTENEGRO

## SUMMARY

This paper presents the use of Erosion Potential Method (EPM) for the prediction of runoff and soil loss in the Lapnjak watershed, Polimlje, Montenegro. Ecological factors, which are the basis for the calculation of soil erosion intensity, we included in the EPM model. This allowed the quantification of the environmental effects of soil erosion. Data concerning runoff and sediment yield from the Lapnjak watershed located in North-East Montenegro are reported. The value of the Z coefficient was calculated on 0.268 and the strength of the erosion process is low. Our results suggest that the calculated maximal outflow from the river basin was 111 $m^3s^{-1}$ for the incidence of 100 years. The net soil loss was 856 $m^3$ per year, specific 124 $m^3km^{-2}$ per year. According to our analysis there is a possibility for large flood waves to appear in the studied river basin. The Erosion Potential method we used in this study is highly recommended for soil erosion modelling in other river basins similar to the studied watershed, because of its simple and reliable identification of critical areas affected by the soil loss caused by soil erosion. It is 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 studied area of the Lapnjak watershed of the Polimlje basin.

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

## INTRODUCTION

The occurrence of natural and anthropogenic extreme phenomena all around the world makes us pay more attention to their environmental and economic impacts (Ristic *et al*., 2012; Schmidt *et al*., 2006; Lerner, 2007). Soil erosion is one of them and is a growing problem in South East Europe, especially in the Mediterranean countries. Land degradation caused by soil erosion is especially serious in Montenegro (Spalevic *et al*, 2014a). According to Kostadinov *et al.* (2006), water erosion has affected 95% of the total territory of Montenegro.

The off-site impacts of runoff and eroded soil, sedimentation, loss of reservoir capacity, flooding are increasing in this Region. Quantitative information on soil loss and runoff is needed for erosion risk assessment. This requires the collection of field data, various measurements, as well as processing

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of those data through the predictive models for the evaluation of different management scenarios for the soil conservation.

We studied soil erosion intensity and runoff of the area of the Lapnjak watershed. This was an important issue as the trends in the Region are demonstrating higher erosion rates in some river basins comparing it with the data of the previous decades.

The important results of this study are 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.*** The Lapnjak watershed encompasses an area of 6.9 km$^2$, with the length of the watershed of 1.7 km. The shortest distance between the fountainhead and the mouth, Lm, is 1.39 km. The total length of the main watercourse, with tributaries of I and II class, ΣL, is 2.34 km.

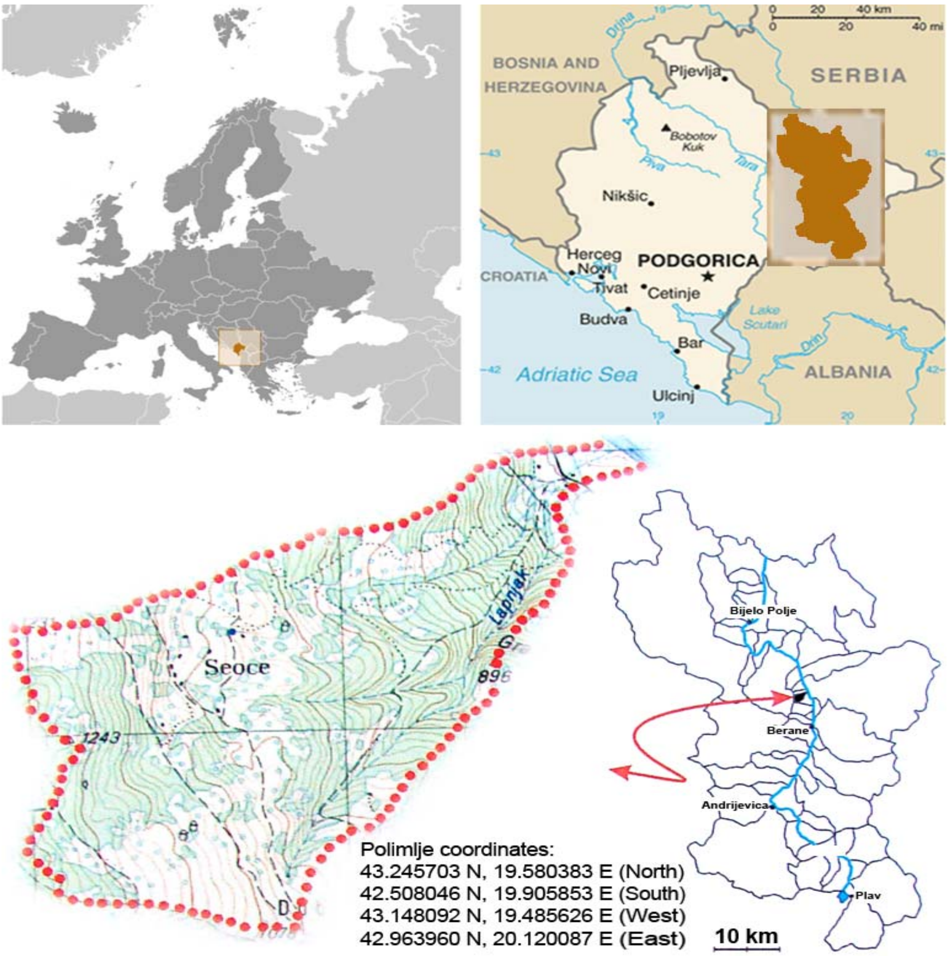


Figure 1: Study area (source: Spalevic, 2011)

***Laboratory analysis.*** Physical and chemical soil properties are all involved in the behaviour of soils and their response to external changes (Parr et al. 1992). The soil and vegetation cover directly affects the intensity of the surface runoff by creating "losses" of precipitation through the processes of interception, evaporation, transpiration and infiltration (Ristic and Macan, 1997).

We drew on the earlier pedological work of the Biotechnical Faculty led by Fustic and Djuretic (2000), who analysed the physical and chemical properties of all Montenegrin soils, including those in the study area. Furthermore, 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 (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).

***Soil loss model application.*** A number of soil erosion models at a watershed scale have been presented by different researchers over the past four decades (Bhattacharya *et al*. 2007) such as Soil and Water Assessment Tool (SWAT) (Neitsch *et al*. 2002), Sediment River Network model (SedNet) (Prosser *et al*. 2001), SHETRAN (Ewen *et al*. 2000), European Soil Erosion Model (EUROSEM) (Morgan *el al*. 1993), Water Erosion Prediction Project (WEPP) (Nearing *et al*. 1989), Agricultural Nonpoint Source pollution model (AGNPS) (Young *el al*. 1987), Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS) (Beasley *el al*. 1980) and Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS) (Knisel, 1980). Most of these models incorporated process-based governing equations of only few processes explicitly and hence, their ability to simulate river basin sediment dynamics at a desired level is limited (Kabir *et al*. 2014).

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. It was created, developed, and calibrated in Yugoslavia (Gavrilovic, 1972).

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.

The erosion coefficient, Z, was calculated as follows:

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

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.

The actual sediment yield was calculated as follows:

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

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 methodology is in use in: Bosnia & Herzegovina, Bulgaria, Croatia, Czech Republic, Italy, Iran, Montenegro, Macedonia, Serbia and Slovenia (Spalevic, 2014b; Kostadinov et al., 2014). The use of this methodology in research on runoff and the intensity of soil erosion have been demonstrated in Montenegro, specifically in the Region of Polimlje (Spalevic *et al*. 2014a, 2014b, 2013a, 2013b, 2013c, 2013d, 2013e, 2013f, 2013g, 2012, 2011, 2008, 2007, 2004, 2003, 2001, 2000a, 2000b, 1999a, and 1999b), Fustic and Spalevic (2000).

The EPM is distinguished by its high degree of reliability in calculating sediment yields as well as reservoir sedimentation (Ristic *et al.,* 2011).

## RESULTS AND DISCUSSION

***Physical-geographical characteristics and erosion factors.*** The Watershed Lapnjak stretches from its inflow to Lim, where Hmin, is 649 m a.s.l., to the tops of the Orlujak, on the South; Krusi on the East; Drenova Glavica, on the North, with the Hmax of 1318 m a.s.l. There is a flat area on the lower alluvial terrace, close to the inflow of Lapnjak watershed to the river Lim, but also in the upper part of the river basin around the village of Seoca, and steep slopes in the upper part of the river basin on the slopes of Orlujak, Krusi and Drenova Glavica. The average slope gradient in the river basin, Isr, is calculated on 28.12%. The average river basin altitude, Hsr, is 907.58 m; the average elevation difference of the river basin, D, is 258.58 m.

***Climatic characteristics.*** The climate in the studied watershed is very variable. The absolute maximum air temperature is 37.8°C, the negative temperatures can fall to a minimum of -28.3°C. 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 71.9 mm. The average annual air temperature, t0, is 8.9°C. The average annual precipitation, Hyear, is 983mm (Source: Data from the Meteorological stations Berane & Bijelo Polje, Institute of Hydrometeorology of Montenegro).

***The geological structure of the area.*** The geological structure of this 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 (Zivaljevic, 1989). The coefficient of the region's permeability, S1, is 0.71.

***Soil characteristics of the area.*** The most common soil type in the studied area are Dystric cambisol (75.18%; 5.15 $km^2$); Calcomelanosol (15.04%; 1.03 $km^2$); Fluvisol (9.78%; 0.67 $km^2$) close to the inflow of Lapnjak to Lim (Fustic, Djuretic, 2000; Spalevic, 2011).

***Land use.*** According to our analysis, portion of the river basin under forest cover is 60%; grass, meadows, pastures and orchards covering 31%; bare land, ploughed land and ground without grass vegetation 9%. The coefficient of the river basin planning, Xa, is 0.46. The coefficient of the vegetation cover, S2, is 0.70. Structure of land use in the Lapnjak watershed is presented in Figure 4.


Figure 2. One of the soil profiles (Spalevic, 2011)

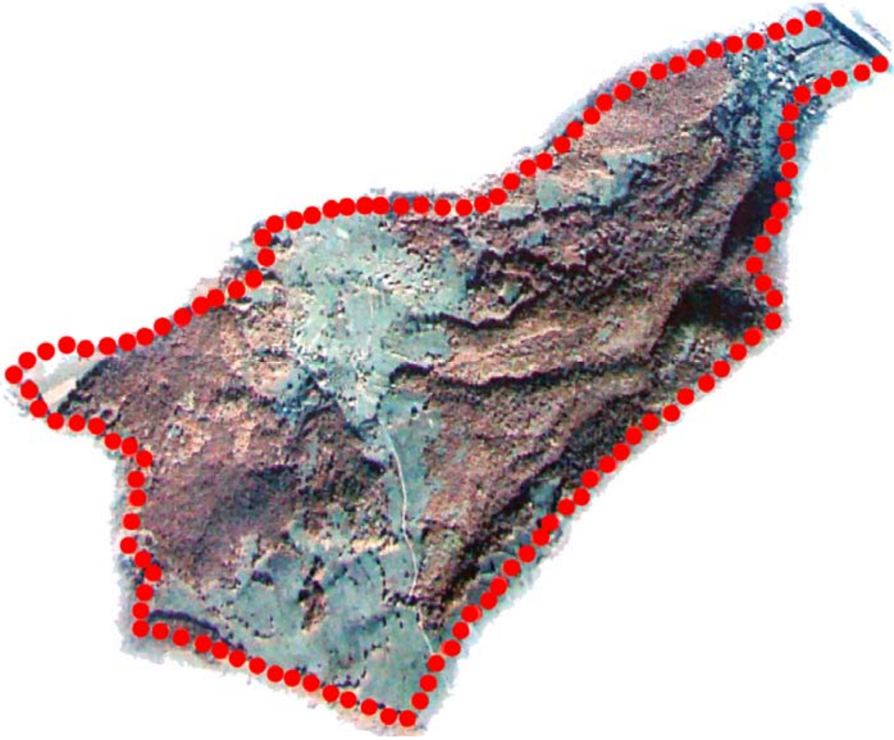

Figure 3: Study area (source: Google maps)

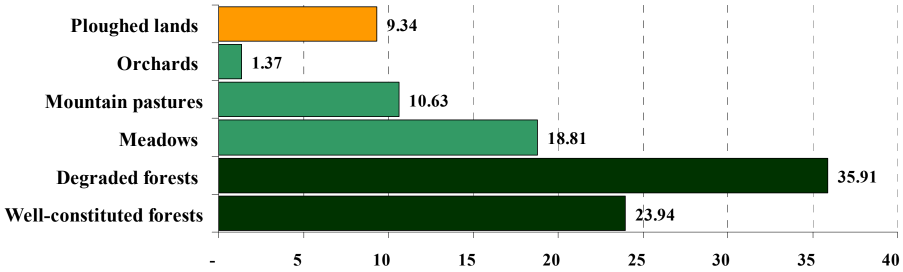


Figure 4. Land use structure of the Lapnjak watershed, % (Source: original)

***Erosion potential method for soil loss modelling.*** We used the EPM model to process the input data required for calculation of the sediment yield and runoff. A report for the Lapnjak watershed basin is presented in the Report 1.

Report 1. EPM report for the Lapnjak watershed basin

**Input data:** River basin area, **F**, 6.9 km²; The length of the watershed, **O**, 11.19 km; Natural length of the main watercourse, **Lv**, 1.70 km; The shortest distance between the fountainhead and mouth, **Lm**, 1.39 km; The total length of the main watercourse (tributaries of I & II class), **ΣL**, 2.34 km; River basin length measured by a series of parallel lines, **Lb,** 4.36 km; The area of the bigger river basin part, **Fv**, 4.9 km²; The area of the smaller river basin part, **Fm**, 2 km²; Altitude of the first contour line, **h0**, 700 m; Equidistance, **Δh**, 100 m; The lowest river basin elevation, **Hmin**, 649 m; The highest river basin elevation, **Hmax**, 1318 m; A very permeable products from rocks (limestone, sand, gravel), **fp**, 0.39; A part of the river basin area consisted of medium permeable rocks, **fpp**, 0.20; A part of the river basin consisted of poor water permeability rocks, **fo**, 0.41; A part of the river basin under forests, **fs**, 0.60; A part of the basin under grass, meadows, pastures and orchards, **ft**, 0.31; A part of the basin under bare land, plough-land and without grass, **fg**, 0.09; The volume of the torrent rain, **hb**, 71.9 mm; Incidence, **Up**, 100 years; Average annual air temperature, **t0**, 8.9 °C; Average annual precipitation, **Hgod**, 983 mm; Types of soil products and related types, **Y**, 0.7; River basin planning, coefficient of the river basin planning, **Xa**, 0.46; Numeral equivalents of visible and clearly exposed erosion process, **φ**, 0.27.

**Results:** Coefficient of the river basin form, **A**, 1.28; Coefficient of the watershed development, **m**, 0.18; Average river basin width, **B**, 1.58 km; (A)symmetry of the river basin, **a**, 0.84; Density of the river network of the basin, **G**, 0.34; Coefficient of the river basin tortuousness, **K**, 1.22; Average river basin altitude, **Hsr**, 907.58 m; Average elevation difference of the river basin, **D**, 258.58 m; Average river basin decline, **Isr**, 28.12 %; The height of the local erosion base of the river basin, **Hleb**, 669 m; Coefficient of the erosion energy of the river basin's relief, **Er**, 131.39; Coefficient of the region's permeability, **S1**, 0.71; Coefficient of the vegetation cover, **S2**, 0.70; Analytical presentation of the water retention in inflow, **W**, 0.9366 m; Energetic potential of water flow during torrent rains, **2gDF^½**, 187.1 m km s; Maximal outflow from the river basin, **Qmax**, 111 $m^3s^{-1}$; Temperature coefficient of the region, **T**, 0.99; Coefficient of the river basin erosion, **Z**, 0.268; Production of erosion material in the river basin, **Wgod**, 2943.5 $m^3$/god; Coefficient of the deposit retention, **Ru**, 0.291; Real soil losses, **Ggod**, 856.06 $m^3$ per year; Real soil losses per $km^2$, **Ggod per km²**, 124.07 $m^3km^{-2}$ per year.

(A)symmetry coefficient, calculated on 0.84, indicates that there is a possibility for large flood waves to appear in the river basin. The value of G coefficient of 0.34 indicates there is low density of the hydrographic network. Average river basin decline, Isr, is 28.97%, what indicates that in the river basin prevails steep slopes.

Calculated maximal outflow from the river basin was 111 $m^3s^{-1}$ for the incidence of 100 years and the net soil loss was 856 $m^3$ per year, specific 124 $m^3km^{-2}$ per year. The strength of the erosion process is weak in the studied area.

According to Babic *et al.* (2003) from the "Jaroslav Cerni" Institute for the Development of Water Resources (JCI), the leading research organisation in Serbia's water sector, real soil losses are 350 $m^3km^{-2}$ per year for the Lim river basin (Polimlje, Fig. 1).

The calculation of the soil losses per $km^2$ in 57 river basins in the North and Northeast of Montenegro was 331 $m^3km^{-2}$ per year (Spalevic, 2011). The result of the real soil losses for the Lapnjak watershed is to some extent lesser in comparison to the other river basin of the North of Montenegro.

The most of the river basins of the north part of Montenegro are categorized in the 4$^{th}$ destruction class, where the strength of the erosion process is weak. In the 57 river basins of Polimlje, where the studied Lapnjak watershed belongs, the following river basins are categorized in the 4$^{th}$ destruction class, (Z coefficient range: 0,25 to 0,30; region of mixed erosion): (02) Komaracka Rijeka; (03) Bijeli Potok; (16) Zlorecica; (17) Krastica; (22) Vinicka Rijeka; (23) Rovacki Potok; (28) Susica; (29) Dapsicka Rijeka; (31) Bosnjak; (32) Tifran; **(33) Lapnjak;** (34) Ljesnica; (35) Karlicica potok; (36) Bioricki potok; (40) Rakljanska rijeka; (41) Duboki potok; (42) Ramcina; (51) Nedakusi.

## CONCLUSIONS

According to the results, it can be concluded that in the studied Lapnjak watershed the most common soil type are Dystric cambisol (75.18%), Calcomelanosol (15.04%), Fluvisol (9.78%).

In terms of land use it can be noted that forest is prevalent form covering 60% of the territory of the studied watershed; grass, meadows, pastures and orchards covering 31%; bare land, ploughed land and ground without grass vegetation 9%.

According to our analysis there is a possibility for large flood waves to appear in the river basin. There is low density of the hydrographic network and in the river basin prevails steep slopes.

Calculated maximal outflow from the river basin was 111 $m^3s^{-1}$ for the incidence of 100 years and the net soil loss was 856 $m^3$ per year, specific 124 $m^3km^{-2}$ per year. The strength of the erosion process is weak in the studied area.

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 Erosion Potential Method is useful tool for researchers in calculation of runoff and sediment yield at the level of the river basins in the regions of South and South East Europe, similar to the studied area of the Lapnjak watershed of the Polimlje basin.

The presented results may serve as valuable contribution for further research in the Region to understand the erosion phenomena and its impact upon the landscape.

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## *OBRAČUN INTENZITETA EROZIJE ZEMLJIŠTA I OTICANJA U SLIVU LAPNJAKA, POLIMLJE, CRNA GORA*

Ovaj rad ukazuje na mogućnost korišćenja metode potencijala erozije kod obračuna intenziteta erozije zemljišta i oticanja u slivu Lapnjaka, Polimlje, Crna Gora. Ekološke faktore, koji su osnov za proračun intenziteta erozije zemljišta, uključili smo u algoritam metode potencijala erozije. To je omogućilo kvantifikovanje uticaja erozije zemljišta na proučavano područje. Vrijednost koeficijenta Z je izračunata na 0,268. Naši rezultati ukazuju na to da je maksimalni oticaj iz sliva 111 $m^3s^{-1}$ za učestalost pojave od 100 godina, a neto gubitak zemljišta je 856 $m^3$ godišnje, specifično 124 $m^3$ $km^{-2}$ godišnje. Pokazano je da metod potencijala erozije može biti uspješno upotrijebljen kod modeliranja i u drugim slivovima, zbog jednostavne i pouzdane identifikacije kritičnih područja zahvaćenih degradacijom zemljišta prouzrokovanom erozijom. Ovaj metod je korisno oruđe koje istrazivači mogu koristiti kod proračuna oticanja i intenziteta erozije u slivovima Jugoistočne Evrope, sličnim proučavanom slivu Lapnjaka iz regiona Polimlja.

**Ključne riječi:** Metoda potencijala erozije, erozija zemljišta, produkcija nanosa, slivovi, Polimlje