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SOIL EROSION IN THE ZIM POTOK WATERSHED, POLIMLJE RIVER BASIN, MONTENEGRO

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Abstract

The negative impact of sediments on the environment and water resources is widely acknowledged with many watercourses in Montenegro and in the South Eastern European Region. To reduce sediment exports from the big river basins discharging to the accumulations, it is essential to identify the sources: critical sub basins and the quantity of its sediment yield and runoff. The off-site impacts of runoff and eroded soil, eutrophication of water bodies, loss of reservoir capacity, muddy flooding of roads and communities, are increasingly recognised. Establishing the correlation between on-site erosion rates with off-site impacts is complicated because of the limited data on soil erosion processes in Montenegro and the dynamic nature of this process over space and time. The use of computer-graphic methods allowed the quantification of the environmental effects of soil erosion. We used modelling of sediment yield and runoff for calculation of soil erosion intensity for a Zim Potok watershed of Polimlje, Montenegro. Ecological factors, which are the basis for the calculation of soil erosion intensity, are included in the IntErO simulation model, with the Erosion potential analytical method of Gavrilovic embedded in the algorithm of this computer-graphic method. Our results shown that the calculated maximal outflow from the river basin may be 144 m^3s^{-1} for the 100 years return time flood. The sediment yield was calculated as 689 m^3yr^{-1}, specific 155 $m^3km^{-2}yr^{-1}$. The important results of this study are the determination of erosion processes in the study watershed and new particular information about the recent state of runoff and sediment yield in formats that can facilitate its efficient management and protection, illustrating the possibility of sediment yield modelling with such approach.

Key words: *Soil erosion, sediment yield, watershed, IntErO model.*

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 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 an especially serious problem in Montenegro and water erosion is the most important erosion type (Spalevic *et al.*, 2014c), due to precipitation and consecutive runoff primarily, but also by fluvial erosion in water streams (Kostadinov *et al.,* 2006). According to Kadovic (1999) water erosion has affected 95% of the territory of Montenegro (13,135 km^2 out of 13,812 km^2). Alluvial accumulation characterises the remaining area of 677 km^2.

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).

The modelling of the erosion process has progressed rapidly, and a variety of models have been developed to predict both runoff and soil loss (Zhang *et al.* 1996). Several software have been developed to predict soil erosion. The authors of this study used the computer - graphic IntErO model (Spalevic, 2011) for prediction of soil erosion intensity and maximum outflow from the catchment area.

The objective of this research is the characterization of the erosion processes in relation to the recent state of the runoff and sediment yield in the Zim Potok Watershed of the Polimlje River Basin. The results are consistent with previous researches of other authors under similar conditions, in formats that may be further used for the efficient management and protection, illustrating the possibility of modelling sediment yield by the IntErO model.

The objective has been met based on literature review, past experience and field measurements at the Polimlje River Basin. Such set of information about the mountainous areas of Montenegro are important for the development of soil protection strategies in the Region. We showed that IntErO can be applied for the assessment of soil erosion at the national scale and may be a useful tool for similar studies in the southern east Region of Europe.

Material and methods

The study is conducted in the River Basin of Zim Potok (Figure 1), a left-hand tributary of the river Lim located in the upper part of the Polimlje region of Montenegro. The whole catchment of the Zim Potok covers an area of 4.5 km^2, with a river length of 0.7 km.

The methodological approach consisted of collection and processing of data related to general characteristics of the area: climate, geological and pedological features, including investigations on the state of vegetation as well as physical and geographical parameters of river channels and river basins.

Simultaneous theoretical, experimental and field research required specific methodological approaches: fieldwork, laboratory and empirical methods, as well as use of computer graphic methods which generated data to predict maximum runoff from the river basins and the intensity of soil erosion.

Fieldwork was undertaken to collect detailed information on specific data needed to calculate soil erosion intensity and runoff.

We drew on the earlier geological research of the Institute of Geology of Montenegro extracting the geological data from the Geological map of Montenegro (Zivaljevic, 1989) related to the structure of the river basin, according to bedrock permeability.

We used the results of the pedological research of the Agricultural Institute in Podgorica led by Fustic and Djuretic (2000), who analysed the physical and chemical properties of all Montenegrin soils in the period from 1964 to 1988, including those in the study area of the Zim Potok River Basin.

Assessment of sediment yield at the catchment scale plays an important role for optimal design of hydraulic structures, such as bridges, culverts, reservoirs, and detention basins, as well as making informed decisions in environmental management. Many experimental studies focused on obtaining flow and sediment data in search of unique relationships between runoff (specifically, volume and peak) and sediment characteristics.

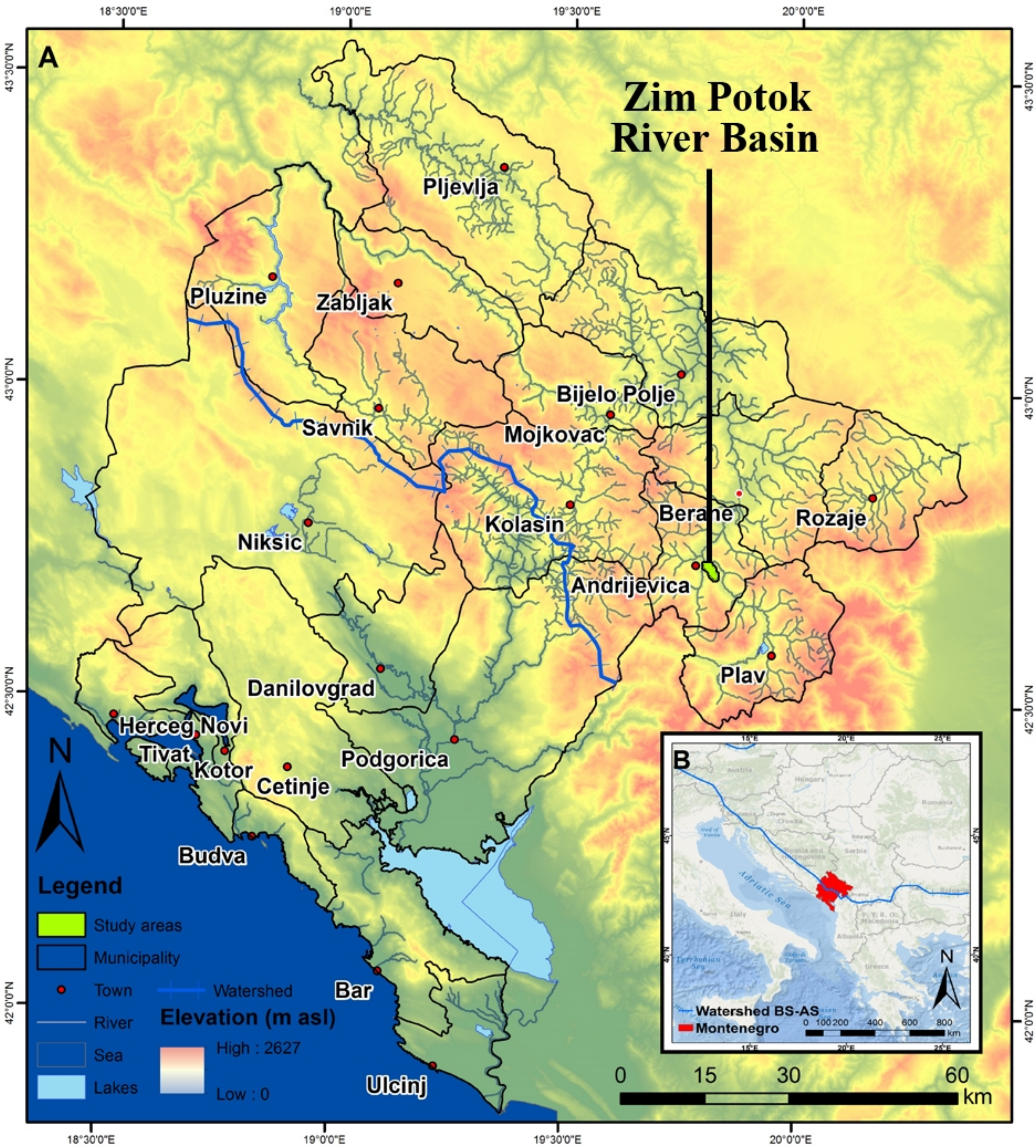

Figure 1. A) Montenegro and the study area subjected to detailed soil erosion research;
B) Position of Montenegro in South-eastern Europe (Lenaerts, 2014).

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 soil erosion intensity has been demonstrated in Montenegro, specifically in the Region of Polimlje (Spalevic *et al*. 2014a, 2014b, 2013a, 2013b, 2013c, 2013d, 2013e, 2013f, 2012a, 2003) and that approach was used in the research on the Zim Potok River basin.

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 (Gavrilovic, S., 1960, 1961, 1964a, 1964b, 1972, Madureiraa *et al*. 2011). We used the program Intensity of Erosion and Outflow - IntErO (Spalevic, 2011) for calculation of soil erosion intensity and forecasting of maximum runoff from the river basin, a programme driven by the Erosion Potential Method (Gavrilovic, 1972).

Results and discussion

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

The river basin of Zim Potok stretches from its inflow to Lim, where Hmin, is 741 m asl, to the tops of the Jerinja Glava, where the Hmax is 1503 m asl. The average slope gradient in the river basin, I_{sr}, is calculated as 44%, indicating that in the river basin very steep slopes prevail. The average river basin altitude, H_{sr}, is calculated as 1036 m asl; the average elevation difference of the river basin, D, is 295.9 m.

The **climate** of the area is characterised by dry summers; rainy autumns and springs; and cold winters. The absolute maximum air temperature is 35°C. Winters are severe, so much so that low temperatures can fall to a minimum of -29.8°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 temperature coefficient of the region, T, is calculated to be 1.00.

Sediment yield is also a function of basin **geological structure**. In the structural-tectonic sense, the study 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. Our analysis shows that the structure of the river basin, according to bedrock permeability, is the following: f0, poor water permeability rocks, 3%; fpp, medium permeable rocks, 40%; fp, very permeable products from rocks: 57%. The coefficient of the region's permeability, S1, is calculated on 0.54.

Based on the previous results of **soil research** (Fustic and Djuretic, 2000; Spalevic, 2011), as well as the original fieldwork and laboratory analysis, we concluded that major soil types in the river basin are Dystric cambisol (71%); Calcomelanosol (13%) and Fluvisol, close to the confluence of Zim Potok into Lim (16%).

Land cover/use and management are the most important factors that influence soil erosion (Gobin *et al.*, 2003). Overall, during the last decades, 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.*, 2014).

Zim river basin forest vegetation is characterized by beech forests *Fagetum montanum*, which dominate on the basin northern slope near Jerinja Glava. With regard to the structure it can be said that stands of the researched area have a structure close to even-aged stands. The dimensions of the beech trees indicate the high production potential of these forests. These stands are characterized by the high cover value of the tree layer (0.7-1.0) (Curovic *et al.*, 2011). The canopy is dominated by beech trees and in some areas maple trees (*Acer pseudoplatanus*), providing little light to the understory. As regards the characteristic species of the herb layers which are typical for these forests, the highest abundance is that of *Asperula odorata*, *Cardamine bulbifera*, *Lamiastrum galeobdolon*, *Anemone nemorosa* etc. In areas with lower pH is a larger number of acidophilic species. Among them, the highest abundance is that of fescue (*Festuca drymeia*), followed by *Oxalis acetosella*, *Lamiastrum galeobdolon* and numerous Bryophytes.

At the higher parts of the basin there are small areas covered by mixed forests of broadleaves and deciduous tree species (*Abieti – Fagetum moesiacae* Blec and Lak.*)*.

According to our analysis, the portion of the river basin under forest cover is 50%; grass, meadows, pastures and orchards covering 48%; bare land, ploughed land and ground without grass vegetation 2%. The coefficient of the river basin planning, Xa, is calculated as 0.34. The coefficient of the vegetation cover, S_2, is calculated as 0.7. Structure of the land use in the Zim Potok watershed is presented in Figure 2.

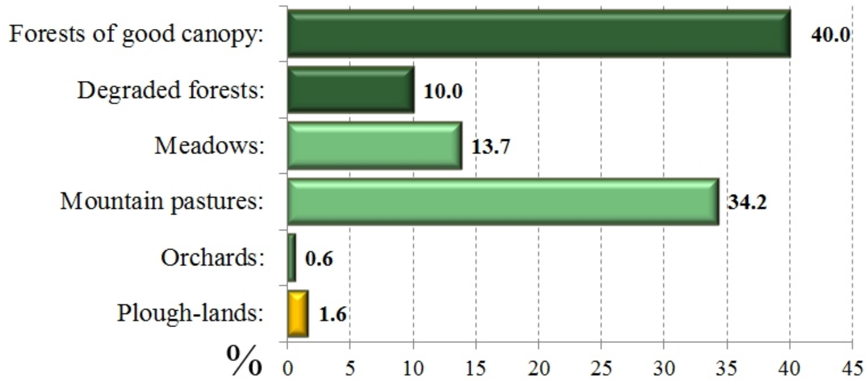

Figure 2. Land use structure of the Zim Potok River Basin (%)

Water-induced **soil erosion** is the result of the complex effect of a whole group of factors. In their research, Baver (1959), Djekovic et al. (2013) showed that erosion intensity is commonly influenced by the land properties and use, increasingly so in the anthropogenous period of their evolution.

The dominant erosion form in the studied river basin is sheet erosion with a removal of a relatively uniform thin layer of soil from the land surface by rainfall and largely un-channelled surface runoff (sheet flow). A small amount of material is washed through the soil, but the more important erosion processes take place at the surface. Material is detached by raindrop impact and flow traction and transported by overland water flow. Final results of the combinations of these detachment and transport processes caused by rainsplash, rainwash, but taking into considerations the other specific climate conditions, physical-geographical conditions of the studied watershed, as well as geological and soil characteristics are presented in the Report 1.

Report 1. Part of the IntErO report for the Zim Potok (without listing on Input data)

Results: Coefficient of the river basin form, **A**, 2.87; Coefficient of the watershed development, **m**, 0.09; Average river basin width, **B**, 1.22 km; (A)symmetry of the river basin, **a**, 0.33; Density of the river network of the basin, **G**, 0.15; Coefficient of the river basin tortuousness, **K**, 1.07; Average river basin altitude, **Hsr**, 1033.84 m; Average elevation difference of the river basin, **D**, 292.84 m; Average river basin decline, **Isr**, 45.96 %; The height of the local erosion base of the river basin, **Hleb**, 762 m; Coefficient of the erosion energy of the river basin's relief, **Er**, 167.15; Coefficient of the region's permeability, **S1**, 0.54; Coefficient of the vegetation cover, **S2**, 0.70; Analytical presentation of the water retention in inflow, **W**, 0.834 m; Energetic potential of water flow during torrent rains, **2gDF^½,** 159.61 m km s; Maximal outflow from the river basin, $\mathbf{Q_{max}}$, 144.4 m^3s^{-1}; Temperature coefficient of the region, **T**, 0.1; Coefficient of the river basin erosion, **Z**, 0.26; Production of erosion material in the river basin, $\mathbf{W_{year}}$, 2186 m^3/god; Coefficient of the deposit retention, **Ru**, 0.316; Real soil losses, $\mathbf{G_{year}}$, 689.96 m^3 per year; Real soil losses per km^2, $\mathbf{G_{year}}$ **per km²**, 155.61 m^3km^{-2} per year.

(A)symmetry coefficient indicates that there is a possibility for large flood waves to appear in the river basin. The value of G coefficient of 0.15, indicates there is low density of the

hydrographic network, what indicates a high infiltration rates which should result in low overland flow and hence low rate of soil detachment.
The value of 45.96% indicates that in the river basin prevail almost vertical slopes.
Runoff is the most important direct driver of severe soil erosion. Processes that influence runoff must therefore play an important role in any analysis of soil erosion intensity. The highest computed peak discharges is 144 m^3s^{-1} (32.5 $m^3s^{-1}km^{-2}$) for a return period of 100 years. Using the option of altering the incidence in the IntErO software, we received the information on the calculated peak flow for the return period of 5, 10, 20, 50 and 100 years (m^3s^{-1}), as presented in the Figure 3.

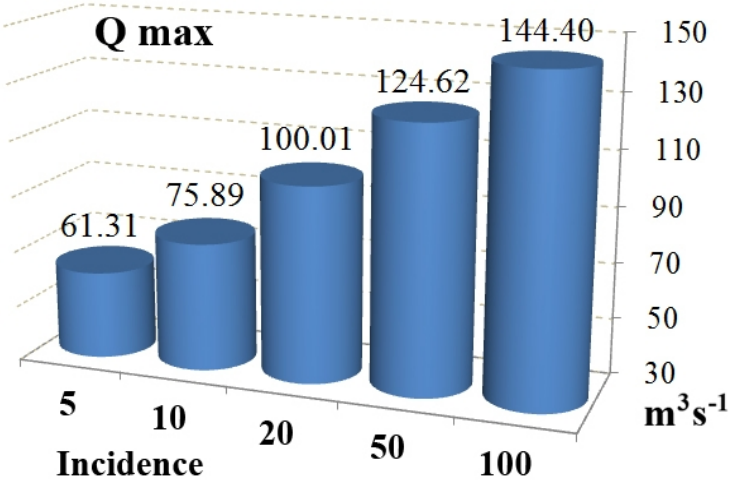

Figure 3. The highest computed peak discharges for the return period of 5, 10, 20, 50 and 100 years (m^3s^{-1})

The value of Z coefficient of 0.260 indicates that the river basin belongs to the fourth destruction category out of five. The strength of the erosion process is low, and according to the erosion type, it is mixed erosion.
Sediment yield at catchment outlet (G_{year}) was calculated as 689.96 m^3year^{-1}; and specific sediment yield at 155.61 $m^3km^{-2}year^{-1}$. According to Gavrilovic classification (1972), the river basin is a region of very weak erosion.

Conclusions

The study was conducted in the area of the Zim Potok River Basin, a left-hand tributary of the river Lim in Montenegro. We calculated the soil erosion intensity and runoff using the IntErO model (Spalevic, 2011). According to our findings, it can be concluded that there is a possibility for large flood waves to appear in the studied Zim Potok River Basin. Calculated peak flow is 144 m^3s^{-1} for a return period of 100 years. The value of Z coefficient of 0.260 indicates that the river basin belongs to the fourth destruction category out of five. The strength of the erosion process is low, and according to the erosion type, it is mixed erosion.
Sediment yield at catchment outlet (G_{year}) was calculated as 689.96 m^3year^{-1}; and specific sediment yield at 155.61 $m^3km^{-2}year^{-1}$. According to Gavrilovic classification (1972), the river basin is a region of very weak erosion.
The results show the importance of considering lithological (the type and characteristics of minerals present) and hydrological (precipitation, water storage capacity of soil, runoff) factors under the current conditions of land usage.
The soil loss rates of the studied Zim Potok River Basin (155 $m^3km^{-2}year^{-1}$) and in the wider Polimlje region: 350 $m^3km^{-2}year^{-1}$, (Babic Mladenovic, 2003); 458 $m^3km^{-2}year^{-1}$ (Fustic and Spalevic, 2000); 111 $m^3km^{-2}year^{-1}$ (Spalevic *et al*. 2014a); 219 $m^3km^{-2}year^{-1}$ (Spalevic *et al*. 2014b); 645 $m^3km^{-2}year^{-1}$ (Spalevic *et al*. 2013a); 115 $m^3km^{-2}year^{-1}$ (Spalevic *et al*. 2013b);

37 $m^3km^{-2}year^{-1}$ (Spalevic *et al*. 2013c); 133 $m^3km^{-2}year^{-1}$ (Spalevic *et al*. 2013d); 315 $m^3km^{-2}year^{-1}$ (Spalevic *et al*. 2013e); 154 $m^3km^{-2}year^{-1}$ (Spalevic *et al*. 2013f); 117 $m^3km^{-2}year^{-1}$ (Spalevic *et al*. 2012a); 121 $m^3km^{-2}year^{-1}$ (Spalevic *et al*. 2003); are very low in comparison to adjacent watersheds of the Coastal zone of Montenegro where the soil loss is around 1900 $m^3km^{-2}year^{-1}$ in some watersheds (Spalevic *et al.*, 2014c; Spalevic *et al.*, 2012b). This shows that vegetation cover and land management in northern Montenegro are effective in protecting the land from erosion as was also observed by Nyssen *et al*. (2014).

The results of this analysis can contribute to the improvement of planning processes and the implementation of development projects in watersheds of the southern east European river basins.

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