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SOIL EROSION IN THE RIVER BASIN OF PROVALA, MONTENEGRO

ABSTRACT

Use of models in the research of soil erosion processes is at the moment a standard practice and models are necessary tool for better understanding of sediment production and runoff, although their interpretation is limited by large uncertainties, including model parameter uncertainties. In this research we studied the main ecological factors and anthropogenic influences in sediment yield on the Provala basin of Montenegro analyzing the relationships between the physical-geographical, geological, soil, land use, climate characteristics and soil erosion intensity. Real soil losses, $G_r$, were calculated on $7541 \, m^3 yr^{-1}$, specific on $597 \, m^3 km^{-2} yr^{-1}$. The value of Z coefficient was calculated on 0.482 what indicates that the river basin belongs to the 3rd destruction category; erosion process is medium. There is a possibility for large flood waves to appear in the studied basin. The results presented in this paper can provide decision support for watershed managers about where the best conservation measures can be implemented effectively and at low cost in the studied area. The methods we used in this study can also be of interest in sediment modeling for other basins in the Region.

Keywords: Erosion, River Basin, Sediment yield, Runoff, IntErO model.

INTRODUCTION

Land degradation caused by erosion processes, combined with fast population growth, according to Stoffel and Huggel (2012), are ranked as the most important environmental problems in the world. The erosion is heavily affecting sustainable land management in various environments globally, having drastic consequences on soil productivity and fertility (Ballesteros-Cánovas et al, 2015; Stoffel et al, 2013).

The South and Southeast regions of Europe are significantly prone to water erosion. In Montenegro water erosion is the most important erosion type. The main forces of water erosion are precipitations and consecutive runoff; but not less important is fluvial erosion in water streams (Kostadinov et al. 2006).
Water erosion has affected 95% of the total territory of Montenegro. Alluvial accumulation characterises the remaining area, where the deposition of sediments is also affecting agricultural land. Erosion caused by water is dominant in terrain with high slopes due to complex physical and geographical conditions paired with reckless logging (Spalevic, 2013a).

According to Blinkov (2015) the most erosive countries in Europe are the Balkan countries Albania and Montenegro, where the mean annual intensity of erosion is more than 10 t ha\(^{-1}\). These findings are confirmed by Spalevic \textit{et al} (2012) for the coastal area of Montenegro (1900 m\(^3\)km\(^{-2}\)yr\(^{-1}\) for the Zeljeznica river basin of the Adriatic Watershed). On the other hand, for the Polimlje (North of Montenegro, the Black Sea Watershed), the calculated soil losses per km\(^2\) for the 57 river basins were in average 331 m\(^3\)km\(^{-2}\)yr\(^{-1}\) (Spalevic, 2011; Spalevic \textit{et al}, 2013a). All the facts stated explains why erosion risk assessment and its quantification is an important question for this Region.

This contribution aims at providing a review of the main ecological factors and anthropogenic influences in sediment yield on the Provala basin of the Polimlje of Montenegro, as a case study, analysing the relationships between the physical-geographical, geological, soil, land use, climate characteristics and soil erosion intensity.

**MATERIAL AND METHODS**

The study was conducted in the Provala drainage basin (12.6 km\(^2\)), a right-hand tributary of the river Lim, located in the mountainous area of the northeastern part of Montenegro (Figure 1).

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, and the measures in place to reduce or alleviate 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 erosion rills.

We drew on the earlier geological (Zivaljevic, 1989) pedological (Djuretic and Fustic, 2000) research, who analysed all geological formations and soils of Montenegro including the studied area of the Provala watershed. Climatological data were received from the Institute of Hydrometeorology and Seismology of Montenegro.
Figure 2. Details from the studied Provala river basin (Mount Balj, the Village Seoce and the view on Andrijevica; photos Velibor Spalevic and Danilo Folic)
The general methodology for modelling soil erosion rates and related sediment yield involved several steps. First, a land use analysis through on-screen visual interpretation. Second, field work using morphometric methods for defining various parameters related to the erosion processes, land use, and the measures taken to reduce or mitigate erosion. Third, laboratory analysis competed. Finally, we applied prediction model to simulate soil erosion and sediment yield in the study area: the IntErO model (Spalevic, 2011).

The analytical equation is based on the following equation:

\[ W_{yr} = T \cdot H_{yr} \cdot \pi \cdot \sqrt{Z} \cdot F \]

where \( W_{yr} \) is the annual erosion in m\(^3\)yr\(^{-1} \); \( T \), the temperature coeff.; \( H_{yr} \), the average yearly precipitation in mm; \( Z \), 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; \( X \) is Soil protection coefficient; \( \phi \) is Erosion development coefficient (tables for \( Y \), \( X \) and \( \phi \) coefficients available at Gavrilovic, 1972). \( F \) is the watershed area in km\(^2\).

The actual sediment yield was calculated as follows:

\[ G_{yr} = W_{yr} \cdot R_u \]

where, \( G_{yr} \) is the sediment yield in m\(^3\)yr\(^{-1} \); \( W_{yr} \) is the total annual erosion in m\(^3\)yr\(^{-1} \); \( R_u \) is sediment delivery ratio.

The actual sediment yield was calculated as follows:

\[ R_u = \frac{(\sqrt{O \cdot D})}{0.2 \cdot (L + 10)} \]

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.

The following required model input parameters were further generated by the IntErO model, receiving sediment yield and runoff predictions: i) Data from the Relief map, Physical-Geographical & Hydrological characteristics of the river basin; ii) Data from the Geological and Soil maps; iii) Land use iv) Meteorological data, including data on rainfall and temperatures.

This methodology is currently in use in: Austria, Bosnia, Brazil, Bulgaria, Croatia, Czech Republic, Iran, Italy, Macedonia, Montenegro, Morocco, Serbia, Saudi Arabia (Al-Turki et al., 2015; Barovic et al., 2015; Barovic and Spalevic, 2015; Behzadfar et al., 2015; Behzadfar et al., 2014a; Behzadfar et al., 2014b; Gazdic et al., 2015; Ristic et al., 2001; Spalevic et al., 2015a; Spalevic et al., 2015b; Spalevic et al., 2015c; Spalevic et al., 2015d; Spalevic et al., 2015e; Spalevic et al., 2015f; Spalevic et al., 2014a; Spalevic et al., 2014b; Spalevic et al., 2014c; Spalevic et al., 2014d; Spalevic et al., 2013b; Spalevic et al., 2013c; Spalevic et al., 2013d; Tazioli et al., 2015; Tazioli, 2009; Kostadinov et al., 2014; Curovic et al., 1999; Vujacic & Spalevic, 2015).
RESULTS AND DISCUSSION

Climate. Various authors acknowledged the effects of climate on land degradation outlining the impacts of precipitations and temperature on soil erosion processes. According to Routschek et al. (2014), soil erosion is mostly the result of extreme but short rainfall events. Analysis of frequency and intensity of these extreme rainfall events are needed for the calculation of sediment yield, and will be more important in the future due to climate change. The impact of the climate change on frequency and extent of soil erosion processes has been estimated by several scientists (e.g. Klik and Eitzinger, 2010; Zhang et al., 2010; Mullan et al., 2012; Nunes et al., 2013). They emphasized fundamental limitations of several previous studies: the spatial and the temporal scale at which climate changes are represented; changes in land use and management.

The climate in the studied area of the Provala drainage basin is continental (absolute maximum air temperature of 35°C; min. -29.8°C). In order to receive the results on sediment yield and runoff for the studied river basin we analysed torrential rains, annual air temperatures, average annual precipitations.

This location is classified as Dfb by Köppen and Geiger.

The amount of torrential rain, hb, is calculated on 115 mm. The average annual air temperature, t0, is 9 °C. The average annual precipitation, Hyr, is 1183 mm. The temperature coefficient of the region, T, is calculated to be 1.00.

Geology and soils.

The study area belongs to the Durmitor geotectonic unit of the inner Dinarides of Northern and North - eastern Montenegro (Frankl et al., 2015). The geological structure of that part consists mainly of Paleozoic clastic, carbonate and silicate volcanic rocks and sediments of the Triassic, Jurassic, Cretaceous – Paleogene and Neogene sediments. The coefficient of the region's permeability, S1, according to the analysis of geological substrate is calculated on 0.98.
Sediment yield is also a function of basin soils structure. Based on the results of pedological research (Fustic & Djuretic, 2000; Spalevic, 2011; Spalevic, 1999), and our own research, the most common soil types in the watershed are: Dystric Cambisols, Kalkomelanosols, Eutric Cambisols, Fluvisols and Colluvial Fluvisols.

The structure of the river basin, according to the soil types is presented at the figure 5.

**Land use.** Soil erosion assessment is taking into consideration high dependencies and interactions between hydrogeomorphic processes and vegetation. Stoffel and Wilford (2012) highlighted the role of vegetation in the initiation of hydrogeomorphic processes and its impact on stream morphology.

Furthermore, acknowledged climate change forces land-use changes, e.g. alteration of land-use structure, crop variety, and time shift in tillage and harvest. This was the reason of our detailed analysis on land use and vegetation cover. According to the data of land use and vegetation cover, received from the Institute of Forestry of Montenegro (IoFoM), Statistical Office of Montenegro (MONSTAT), Google Maps and our own research, the Provala drainage basin is mainly covered by grass, covering the area of 51% of the studied river basin.

The diverse forms of forests cover about 45% of the watershed, leaving mainly valley plains and the top of the mountains unwooded. Forest vegetation is consisted of broadleaf tree species. On northern exposures are mainly beech forests - *Fagetum montanum*, while the southern exposures characterize forests of sessile oak and Turkish oak - *Quercetum petraea-cerris*. Beech forests are characterized by the high value of the tree layer canopy, 0.7-1.0, which is characteristic for the most of beech forests in northern part of Montenegro (Curovic et al., 2011). Most of beech forests of the river basin are low forests with coppice origin. At higher altitudes there are areas with the higher site index and which are covered by high beech forests.

Forest of Sessile and Turkish oak: *Quercetum petraeae-cerris* are dominated by *Quercus cerris* followed by *Quercus petreae*, *Carpinus betulus* and other xerophytes tree species. The shrub layer is composed of thermophilous shrubs, mainly *Crataegus* spp., *Cornus* mass, *Prunus spinosa*, *Rosa canina*, etc. The herb layer is typically dominated by *Poa angustifolia*, *P. nemoralis*, *Festuca sp.* etc. These forests are characterized by slightly less value of the tree layer canopy than beech forests.
Soil erosion in the river basin of Provala, Montenegro

Arable land covers a total surface area of only 4%, concentrated in the areas with low slope gradients. The detailed structure of the river basin, according to the land use is presented at the Figure 6.

**Figure 6: The structure of the river basin, according to the land use**

**Soil erosion characteristics.** 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 more important erosion processes take place at the surface. Some problems of overgrazing and livestock traces are recorded also, in the areas close to the village Seoce. 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 are presented in the Table 1.

**Table 1. Part of the IntErO report for the Provala Watershed**

| Inputs                                      |          |
|---------------------------------------------|----------|
| River basin area                            | F 12.62  |
| The length of the watershed                 | O 20.73  |
| Natural length of the main watercourse      | Lv 1.24  |
| The shortest distance (fountainhead and mouth) | Lm 1.2   |
| River basin length measured by a series of parallel lines | Lb 7.31  |
| The area of the bigger river basin part     | Fv 7.5   |
| The area of the smaller river basin part    | Fm 5.12  |
| Altitude of the first contour line          | h0 800   |
| The lowest river basin elevation            | Hmin 726 |
| The highest river basin elevation           | Hmax 1601|
| Very permeable products from rocks          | fp 0.69  |
| Medium permeable rocks                      | fpp 0.09 |
| Poor water permeability rocks               | fo 0.22  |
| A part of the river basin under forests     | fs 0.45  |
| A part under grass, meadows, pastures and orchards | ft 0.51 |
| A part under bare land and ground without grass | fg 0.04 |
| The volume of the torrent rain              | hb 115   |
| Average annual air temperature              | t0 9 °C  |
| Average annual precipitation                | Hyr 1183.7|
| Types of soil products and related types    | Y 1.3    |
| Coefficient of the river basin planning     | Xa 0.35  |
| Numeral equivalents of visible erosion process | φ 0.38 |
| Parameter                                                                 | Symbol | Value     |
|--------------------------------------------------------------------------|--------|-----------|
| Coefficient of the river basin form                                      | A      | 3.27      |
| Coefficient of the watershed development                                 | m      | 0.1       |
| Average river basin width                                                | B      | 1.73 km   |
| (A)symmetry of the river basin                                           | a      | 0.38      |
| Density of the river network of the basin                                 | G      | 0.1       |
| Coefficient of the river basin tortuousness                               | K      | 1.03      |
| Average river basin altitude                                             | Hsr    | 1078 m    |
| Average elevation difference of the river basin                           | D      | 352.01 m  |
| Average river basin decline                                              | Isr    | 48.17 %   |
| The height of the local erosion base of the river basin                  | Hleb   | 875 m     |
| Coefficient of the erosion energy of the basin's relief                  | Er     | 147.78    |
| Coefficient of the region's permeability                                 | S1     | 0.56      |
| Coefficient of the vegetation cover                                      | S2     | 0.72      |
| Analytical presentation of the water retention in inflow                 | W      | 1.3957 m  |
| Energetic potential of water flow during torrent rains                   | 2gDF^½ | 295.18 m km s |
| Temperature coefficient of the region                                    | T      | 1         |
| Coefficient of the river basin erosion                                   | Z      | 0.482     |
| Production of erosion material in the river basin                         | Wyr    | 15684 m³ yr⁻¹ |
| Coefficient of the deposit retention                                     | Ru     | 0.481     |
| Real soil losses                                                         | Gyr    | 7541 m³ yr⁻¹ |
| Real soil losses per km²                                                  | Gyr (km²) | 597 m³ km⁻² yr⁻¹ |

The coefficient of the river basin form, A, is calculated on 3.27. Coefficient of the watershed development, m, is 0.1 and average river basin width, B, is 1.72 km. (A)symmetry of the river basin, a, is calculated on 0.38 and indicates that there is a possibility for large flood waves to appear in the river basin. The height of the local erosion base of the river basin, Hleb, is 875 m. Coefficient of the erosion energy of the river basin's relief, Er, is calculated on 147. The value of Z coefficient of 0.482 indicates that the river basin belongs to III destruction category. The strength of the erosion process is medium, and according to the erosion type, it is surface erosion.

We calculated the soil losses from the Provala catchment on 7541 m³ yr⁻¹, specific: 597 m³ km⁻² yr⁻¹.

**CONCLUSIONS**

The overall aim of this research was to investigate the soil erosion risk within the Provala drainage basin as one of the exemplary drainage basin from the region of Andrijevica valley, close to the Prokletije Massif, by means of modelling techniques implemented in a computer-graphics environment.

With 7541 m³ yr⁻¹ of annual sediment yield, corresponding to an area-specific sediment yield of 597 m³ km⁻² yr⁻¹, the Provala drainage basin belongs to the Montenegrin basins with the medium sediment discharge. The value of Z coefficient was calculated on 0.482 what indicates that the river basin belongs to the 3rd destruction category (of five); erosion process is medium. There is a possibility for large flood waves to appear in the studied basin.

The application of the IntErO model in the Provala catchment confirms the suitable performance of this approach to predict sediment yield. The authors can
state that the application of this model allows a simple risk assessment of soil erosion processes. The results presented in this paper can provide decision support for watershed managers about where the best conservation measures can be implemented effectively and at low cost in the studied area. The methods we used in this study can also be of interest in sediment modeling for other basins in the Region of Southern East Europe.

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