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Original Article

# Variability of Soil Erosion Intensity Due to Vegetation Cover Changes: Case Study of Orahovacka Rijeka, Montenegro

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**Abstract**

Vegetation cover change in all the river basins leads to the changes of hydrologic response, soil erosion and sediment dynamics characteristics. Those changes are often viewed as main cause of anthropogenic and accelerated erosion rates in short term and one of the main reasons of climate change in long term. The effects of vegetation cover changes on various parts of water balance and hydrological cycle has to be deeply studied because of its important role on mankind future. The aim of present research was therefore to simulate the responses of soil erosion processes by using a process-oriented soil erosion model IntErO, with the different settings of land use for the years 1977, 1987, 1997, 2006 (2007) and 2016 (2017) in Orahovacka Rijeka watershed; a pilot river basin of the Polimlje Region for the northeastern part of Montenegro. For the current state of land use, calculated peak discharge for the Orahovacka Rijeka was 174-175 $m^3 s^{-1}$ (the incidence of 100 years) and there is a possibility for large flood waves to appear in the studied basin. Real soil losses, Gyear, were calculated on 2614-2921 $m^3 year^{-1}$, specific 229-256 $m^3 km^{-2} year^{-1}$ (1977-2017). The value of Z coefficient range from 0.444 to 0.478 and 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. According to our analysis the land use changes in the last 40 years influenced the increase of the soil erosion intensity for 11% in the study watershed. Further studies should be focused on the detailed analysis of the land use changes trends with the other river basins at the national level, closely following responses of soil erosion to the changed land use structure. The results and approach also should be used by policymakers in all national natural resources organizations to highlight the role of management.

***Keywords:*** IntErO model; land cover; land use; soil erosion; vegetation

## Introduction

Soil erosion is a complex gradual process that occurs when the impact of water detaches and removes soil particles causing the soil to deteriorate (Halecki *et al.*, 2018). The phenomenon constitutes a major global environmental problem (Efthimiou, 2018), together with rapid population increase, are ranked as the most important environmental problems in the world (Andjelkovic *et al.*, 2017; Stoffel and Huggel, 2012) where the erosion is a key driver of land degradation heavily affecting sustainable land management in various environments worldwide (Verheijen *et al.*, 2009; Stoffel *et al.*, 2013; Ballesteros-Cánovas *et al.*, 2015). Human activities could change the earth's surface

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significantly so that soil erosion and sediment dynamics would also be changed correspondingly. The negative effects of soil erosion on agricultural productivity and ecosystem are almost invisible over shorter period of time (Haase *et al.*, 2007; Kisic *et al.*, 2010; Willaarts *et al.*, 2012; Djekovic *et al.*, 2013). There is no need to be aware on the consequences, before realizing the problems, and that is sometimes after decades, when it is, in principle, too late, or too expensive to solve it. In the long term such processes may lead to changes in the provision of ecosystem services.

The present study has been focused on how the past land use variants, over a 40 years' time period (1977-2017), influenced soil erosion process and runoff in the river basin of Orahovacka Rijeka in Montenegro, looking for solutions as to how these findings could be used to predict or optimize future land and water management options in the wider region.

The analysis based on gauging data cannot identify the effects of land use changes to soil erosion and sediment dynamics. Thus, quantification of the responses of soil erosion and sediment yield on land use variations can only be achieved by numerical simulation of soil erosion processes (Zarea *et al.*, 2017; Glavan *et al.*, 2013).

In their 2009 study, Volk *et al.* (2009) encouraged researchers to conduct such analysis highlighting the importance of achieving the aims of the European Water Framework Directive. According to this directive, land use and land management options are to be used as tools for water quantity and quality control in order to achieve and maintain ecologically stable and productive water bodies. This idea on policy issues has been well received among researchers in Montenegro and Serbia taking into consideration the current EU accession agenda of these two countries.

The objective of this research was to simulate responses of soil erosion processes with the different settings of the land use in the River Basin of Orahovacka Rijeka by using a process-oriented soil erosion model IntErO (Spalevic, 2011). The model provides a fast, effective and affordable insight into the effects of land use change on soil erosion processes and sediment yield. Simulation results under different scenarios of land use change was used to analyze the response characteristics of soil erosion processes to the variations in land use with the aim of optimizing current and future land use options. Testing of the applied procedures was important for the further establishing of the watershed management methodologies at the national level, for the other 300 river basins of Montenegro.

**Materials and Methods**

North eastern Montenegro is, in part, very mountainous, with the presence of deeply incised valleys in Limestone Mountains. In this region the highest peaks of Montenegro are found, including Komovi (2487 m a.s.l.) and Zla Kolata (2535 m a.s.l.) in the Prokletije Mountains (Frankl *et al.*, 2015). Rivers in this region drain to the Black Sea.

This study on the impact of land use changes on soil erosion was conducted in the area of the river basin of Orahovacka Rijeka (Fig. 1), a left-hand tributary of the river Lim.

This watershed encompasses an area of 11.5 km$^2$, with the highest peaks of Dedovina and Ceskovina (1331 m, 1308 m) along the southern watershed boundary, then sloping easterly to the villages Kovacevici and Vukotici, in the upper part of the river basin, with the villages Jablanovici and Knezevici further downstream to the East. The natural length of the main watercourse, Lv, is 5.2 km. The shortest distance between the watershed boundary and the mouth, Lm, is 4.1 km.

Morphometric methods were used to determine the slope, the specific lengths, the exposition and form of the slopes, the depth of the erosion base and the density of erosion rills. After identification of physical-geographical features during filed visits, Google Earth was used to further investigate the morphology of the features with realistic 3D view. In that manner, some minor sites or phenomena that were not noted during the fieldwork were also taken into consideration.

According to Chang *et al.* (2009), Google Earth is considered as more than adequate to allow a characterization of identified soil erosion processes.

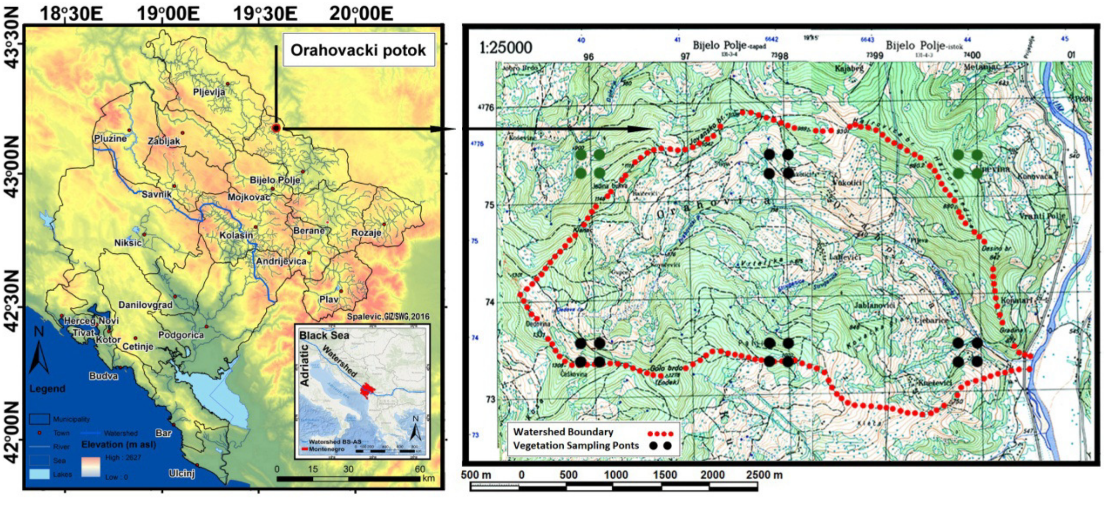


Fig. 1. Study area of the Orahovacka Rijeka river basin with the position of clusters

Some pedological profiles were excavated, and soil samples were collected for physical and chemical analysis. The granulometrical composition of the soil was determined by the pipette method; 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; the content of the total organic matter 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 (Jakovljevic *et al*., 1995).

In order to collect data on current status of vegetation 4 clusters in the area of the basin have been measured: Cluster No 1, near village Knezevici; Cluster No 2, near village Vukotici, Cluster No 3, locality Paljika and Cluster No 4, under the hill of Ceskovina. The clusters network with the sample plots is spread through entire river basin and is based on a basic raster – a regular 2×2 km square raster. On each square raster, there is the cluster comprising four sample plots, circles with radius of r4=17.84 m (p4=10 acres) positioned in the tops of the square whose leg length is 200 m. It was set up 4 clusters.

In order to describe variability of soil erosion intensity due to vegetation cover changes in this river basin, a series of data from The First National Forest Inventory of Montenegro (Dees *et al*., 2013), Forest Management Plans, Cadastre, Landsat images and Statistical Yearbooks that characterize variations in land use in five time profiles: 1977, 1987, 1997, 2007, 2017 have been used.

The soil erosion processes can be to some extent controlled by appropriate land management. This requires the collection of field data and use of predictive models 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, but modelling of the erosion process may adequately predict both the runoff and soil loss. The end of the last century was regarded as the period of research at the national and international level in relation to modelling of the soil erosion process (Batista *et al.*, 2017).

Many of the models for predicting soil erosion and sediment yield were developed to investigate the role of agricultural practices on the process (Bagherzadeh *et al*., 2011). One of the first models was the Universal Soil Loss Equation or USLE (Wischmeier and Smith, 1978). The most common models now being used are RUSLE (Revised Universal Soil Loss Equation), MUSLE (Modified Universal Soil Loss Equation), MUSLT (Theoretical Modified Universal Soil Loss Equation), WEPP (Water Erosion Prediction Project), PSIAC (Pacific South-west Interagency Committee) and EPM (Erosion Potential Method).

Most European, national and regional assessments of soil loss use models, usually a derivate of the Universal Soil Loss Equation - USLE (Wischmeier and Smith, 1978), to estimate long-term averages of annual soil loss by water through small rill and sheet erosion (Steinhoff-Knoppa & Burkhard, 2018); United Kingdom, Germany and France are using their domestic/national models.

In Serbia and Montenegro, for mapping the intensity of water erosion the Erosion Potential Method (EPM) is the preferred as national model (Gavrilovic, 1972). The model is based on the long-term research of the soil erosion process in the Grdelica Gorge, led by professor Gavrilovic. It is important to highlight that the EPM has also been tested in some catchment areas in Italy (Tazioli, 2009) and repeatedly in Iran, and the researchers concluded that the results are compatible with field observation (Sadeghi, 2005; Bagherzadeh *et al.*, 2011; Kouhpeima *et al.,* 2011; Zia Abadi and Ahmadi, 2011; Barovic *et al.,* 2015; Amini *et al.*, 2014; Behzadfar *et al.,* 2014).

In recent times, Blinkov & 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. According to their findings, EPM was the most suitable on catchment level for the watershed management needs in the Region of Southern East European Countries. It is in use in Bosnia & Herzegovina, Croatia, Montenegro, Macedonia, Serbia and Slovenia, but also in Brazil (Guiçardi *et al*, 2017), Italy, Malawi, Morocco. The EPM is distinguished by its high degree of reliability in calculating sediment yields.

The use of Erosion Potential Method (EPM), as well as computer graphics in research on runoff and intensity of soil erosion, have been demonstrated in Montenegro, specifically in the Region of Polimlje (Spalevic, 2011; Vujacic *et al.*, 2015). The Intensity of Erosion and Outflow (IntErO) program package (Spalevic, 2011) was used to obtain estimates of soil erosion intensity in the river basin of Orahovacka Rijeka. The method has clearly defined procedures, and subjective evaluations are reduced to a minimum. The EPM is embedded in the algorithm of IntErO computer-graphic method. Evaluation of the applicability of soil erosion models especially in watershed scale needs to the accurately measures of soil erosion in the field (Sadeghi *et al*., 2013). In contrast, models with the ability to estimate sediment yield are easier to calibrate and apply, because the data for these models can be measured at the watershed outlet easier than soil erosion at the various parts of the watershed area (Erskine *et al.,* 2002; Fontes *et al.,* 2004; Kinnell, 2010) which IntErO is one of the models with such the abilities.

In order to carry out model verification for the subject area, sediment yields were calculated with the IntErO model on 347,273 $m^3$ $year^{-1}$ for all the 57 river basins of the Polimlje region in Montenegro.

The calculations for the Polimlje region, which includes the Orahovacka Rijeka basin, correspond to measurements obtained at the Potpec accumulation (350.000 $m^3$ $year^{-1}$). This correspondence suggests that the assessment results for actual losses of soil erosion potential obtained by IntErO model are eligible for the Orahovacka Rijeka river basin study area.

Besides, Babic *et al.* (2003) calculated real soil losses for the total Lim River basin at 350 $m^3$ $km^{-2}$ $year^{-1}$. By using the IntErO model it has been found that the average value to be 331.78 $m^3$ $km^{-2}$ $year^{-1}$ for the 57 river basins of Polimlje in Montenegro (Spalevic, 2011) and 256 $m^3$ $km^{-2}$ $year^{-1}$ for the studied Orahovacka Rijeka river basin (Table 1 / No 55).

Table 1. Calculated soil losses per km$^2$ in 57 river basins of Polimlje (m$^3$ km$^{-2}$ year$^{-1}$)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **(1)** | 645,40 | **(12)** | 278,33 | **(23)** | 324,45 | **(34)** | 325,19 | **(45)** | 212,39 | **(56)** | 269,25 |
| (2) | 521,84 | **(13)** | 427,63 | **(24)** | 212,67 | **(35)** | 195,47 | **(46)** | 254,63 | **(57)** | 413,66 |
| (3) | 104,31 | **(14)** | 330,12 | **(25)** | 385,41 | **(36)** | 264,43 | **(47)** | 200,43 | | |
| (4) | 288,97 | **(15)** | 429,10 | **(26)** | 492,68 | **(37)** | 286,07 | **(48)** | `514,60 | | |
| **(5)** | 562,60 | **(16)** | 403,46 | **(27)** | 232,47 | **(38)** | 327,04 | **(49)** | 200,56 | | |
| (6) | 399,52 | **(17)** | 370,61 | **(28)** | 305,76 | **(39)** | 452,92 | **(50)** | 247,93 | | |
| (7) | 328,96 | **(18)** | 244,32 | **(29)** | 268,09 | **(40)** | 210,32 | **(51)** | 140,64 | | |
| (8) | 180,22 | **(19)** | 219,39 | **(30)** | 266,21 | **(41)** | 131,23 | **(52)** | 315,28 | | |
| **(9)** | 327,69 | **(20)** | 286,90 | **(31)** | 197,99 | **(42)** | 122,48 | **(53)** | 216,30 | Average | |
| **(10)** | 298,19 | **(21)** | 88,66 | **(32)** | 296,45 | **(43)** | 194,76 | **(54)** | 250,39 | **331,78** | |
| **(11)** | 417,68 | **(22)** | 470,42 | **(33)** | 255,60 | **(44)** | 198,08 | **(55)*** | *256,22 | m$^3$ km$^{-2}$ year$^{-1}$ | |

* *Orahovacka Rijeka; Source*: Original; Spalevic *et al.* (2013); Spalevic (2011) and Spalevic *et al.* (2015).

This correspondence suggests that the results of the assessment obtained by IntErO model are eligible for the study area.

Tazioli (2009) undertook a comparison between the Gavrilovic EPM model and direct measurements of sediment transport. 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 Orahovacka Rijeka river basin that was studied), allowing for an assessment of erosion in the whole watershed.

The values of sediment yield at the studied area of north of Montenegro are 5 to 6 times less than for the river basins of the coastal area of Adriatic, where the values vary from 1800 to 2000 m$^3$ km$^{-2}$ year$^{-1}$ and where the watersheds belongs to the category I and II destruction class, of five (Spalevic *et al.*, 2013).

## Results and Discussion

### *Physical-geographical characteristics*

The river basin of Orahovacka Rijeka stretches from its inflow to the Lim ($H_{min}$, 544 m) to the tops of the Dedovina, where the $H_{max}$ is 1331 m (Figs. 2, 3, 4). There are a flat area in and around the village of Ljebarice and steep slopes in the upper part of the river basin including the villages of Kovacevici and Vukotici. The average river basin decline, $I_{sr}$, is calculated at 32.55% and indicates that very steep slopes prevail in the river basin. The average river basin altitude, $H_{sr}$, is calculated at 863 m; the average elevation difference of the river basin, D, is 319 m.

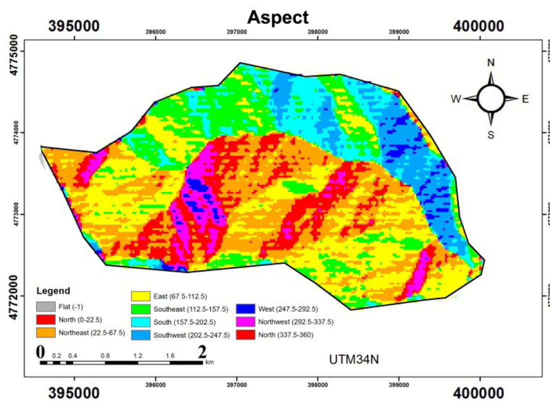


Fig. 2. Aspects, river basin of the Orahovacka Rijeka

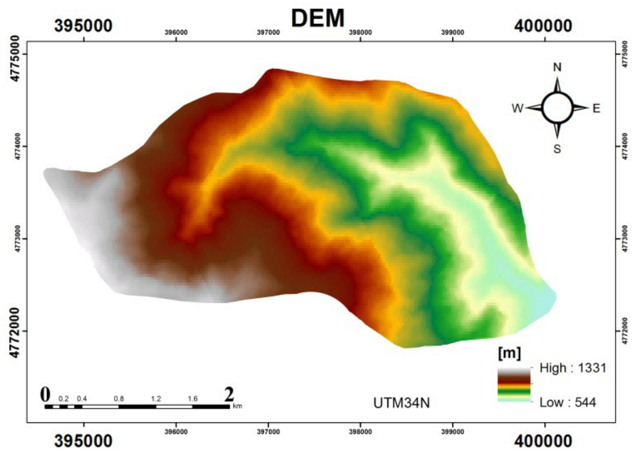


Fig. 3. Digital elevation model for the studied River basin of the Orahovacka Rijeka

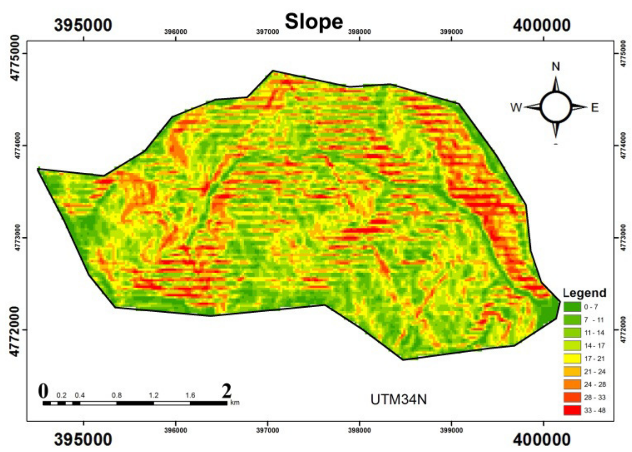


Fig. 4. Slope, river basin of the Orahovacka Rijeka

### *Climatic characteristics*

It is well well-known fact that the precipitations and runoff are direct driving forces of soil erosion and sediment transport. By analysing 70 years of observed temperature and precipitation (1948-2017), it can be clearly concluded that the studied area is characterised by rainy autumns and springs; and cold winters.

The absolute maximum air temperature is 39.2 °C. Winters are severe, so much so that negative temperatures can fall to a minimum of -27.6 °C. The average annual air temperature, $t_0$, is 8.9 °C. The average annual precipitation, $H_{year}$, is 873 mm. Temperature coefficients for the region, T, is calculated at 0.99. The torrential rain, hb, is calculated at 157 mm.

*The geological structure and soils of the area*

This research takes into account a significant influence of geological structure of the terrain on the soil erosion process in terms of permeability and erodibility of rocks.

Montenegro is a part of the Dinaric Alps, which are in turn parts of the complex thrust-and-fold system of the Mediterranean area. This area represents a proxy of long-lasting interactions between Eurasia and Gondwana, resulting in a system of fold-and-thrust belts and associated foreland and back-arc basins. The system cannot be interpreted as the end product of one single Alpine orogeny as the major suture zones result from various tectonic events which closed different oceanic basins, all a part of the former Tethyan Ocean. The Dinarides-Albanides-Hellenides orogenic belt is caused by a Tertiary collision between the Adriatic promontory and the Serbo-Macedonian-Rhodope blocks. The belt is bordered to the west by a foreland basin in the Eastern Adriatic basin filled with Eocene-Quaternary deep marine sediments (Cavazza *et al.*, 2004). Wider territory around the studied area consists of various types of sediment, magmatic and metamorphic rocks generated in the period from Palaeozoic to Quaternary.

The coefficient of the region's permeability, S1, is calculated to be 0.98. Within the studied basin, the area dominates with poor permeability rocks (class fo – 92%) and semipermeable rocks (class fpp) covered 8% of the territory.

*Soil characteristics of the area*

According to the results of the filed visits and supplementary laboratory analysis (Spalevic, 2011), but also using the previous research data of the project Soils of Montenegro (1964-1988) of the team of the Biotechnical faculty (Fustic & Djuretic, 2000), the most common soil types in the studied river basin are: *Dystric Cambisols*; close to the inflow of Orahovacka Rijeka to Lim, *Fluvisols* and *Colluvial Fluvisols*.

*Vegetation and land use*

In Montenegro, vegetation distribution is strongly influenced by (i) the distance to the Mediterranean Sea (continental or maritime climate) and (ii) the altitude (temperate or mountain climate).

Owing to Montenegro's rugged topography, there are large differences in vegetation over short distances (Wraber, 1983). The Orahovacka rijeka river basin is located in Dinaridi Province of the Middle-Southern-East European mountainous biogeographical region. Forests dominate this river basin accounting for 51% of the total vegetation cover.

Most of the river basin is covered by forests of Sessile oak and Turkish oak (*Quercetum petraeae cerridis* Lak.) which are characterized with presence of many different species. On higher altitudes there are degraded beech forests (*Fagetum montanum*). The degraded forests are located near settlements and roads because of the common practice firewood harvesting. These forests are characterized by terminate canopy and by a large number of species of ground flora, shrubs and lower trees (Fig. 5). They differ from beech forests within the basin, especially the sub-association *Fagetum montanum typicum* which are characterized by dense canopy (Curovic *et al.*, 2011). A narrow belt near the river bad in the lower part of the river basin is covered with hydrophilic forest (*Alnetea glutinosae, Salicetea herbacea*).

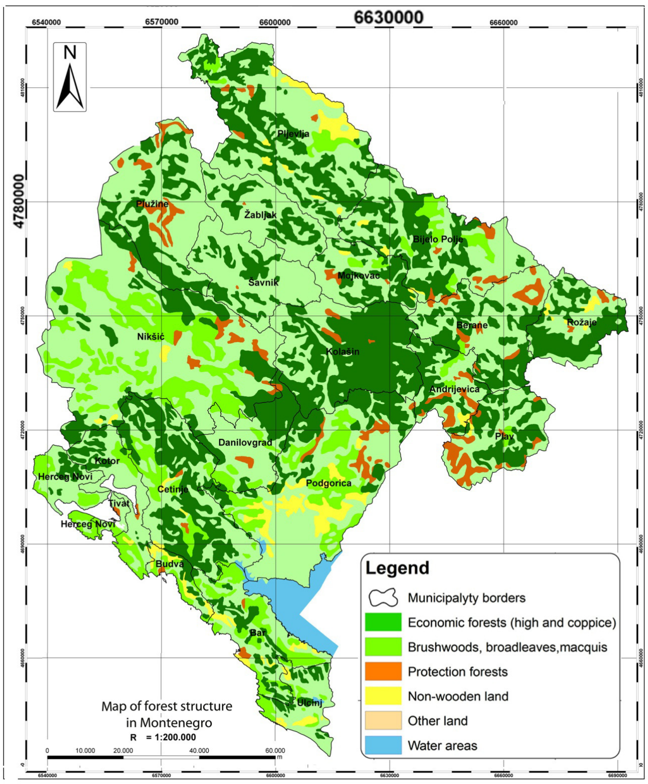


Fig. 5. Map of vegetation cover - forest structure in Montenegro

Four clusters in the area of the basin were measured. Data obtained by measurement show that it mainly contains degraded forests. The average timber volume in the forests is 48,4-133,2 $m^3$ $ha^{-1}$ with 480-1934 trees per hectare. In the Orahovacka rijeka basin *Betula verrucosa, Carpinus betulus, Acer campestre, Populus tremula, Acer tataricum* and *Pyrus pyraster* have been also recorded. The trend of devastation of forests was recorded on 1977, 1987 and 1997. The migration of the rural population to towns in recent years, according to the analyses in the period from 2000 to 2017 resulted in stabilisation of the forest area on 51% (Fig. 6).

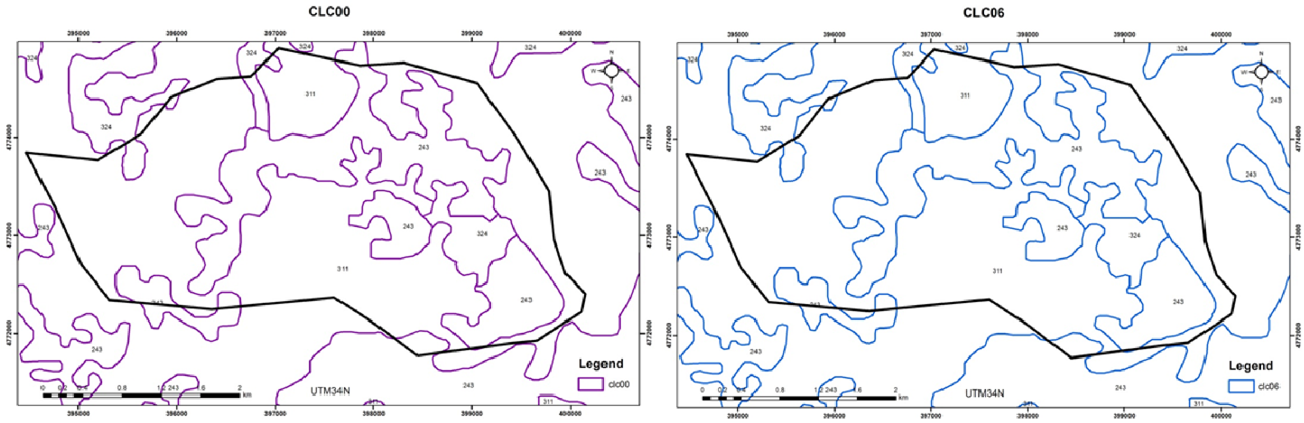


Fig. 6. Status of vegetation cover on 2000 and 2006: CLC classes: 311 – Well constituted forest; 324 – Degraded forest; 243 – Agricultural land, meadows, pastures and orchards

External coordinates: Hmin, X 6644708.0, y 4773950.9; SZ, X 6644262.8, Y 4773639.3; Trig 750, X 6643993.9, Y 4773601.1; Kleca, X 6643060.8, Y 4773442.1; Kleca W, X 6642602.8, Y 4773760.1; Trig. 1020, X 6642189.4, Y 4774008.1; Golo brdo, X 6640949.22, Y 4773842.8; Ceskovina, X 6639909.4, Y 4773900.0; Dedovina, X 6639610.4, Y 4774244.4; T 1301, X 6639317.9, Y 4774828.6; T 1277, X 6639006.2, Y 4775375.5; Klanac, X 6639737.6, Y 4775324.7; T 1178, X 6640170.1, Y 4775610.9; Fagus, X 6640456.3, Y 4775992.5; Jovansko W, X 6640920.6, Y 4776196.0; Jovansko, X 6641264.1, Y 4776234.2; Jovansko E, X 6641531.2, Y 4776533.1; Trig. 989, X6642370.7, Y 4776386.8; Hajrovica, X 6642815.9, Y 4776431.3; Hajrovica Center, X 6643566.4, Y 4776246.9; Hajrovica, X 6643998.9, Y 4775693.5; Desino brdo, X 6644335.9, Y 4775172.0; Konatar, X 6644405.9, Y 4774675.9; Gradina, X 6644533.1, Y 4774338.9; Hmin, X 6644743.0, Y 4774135.3).

Table 2. Cluster Nº 1 - (near village Knezevici)

| Species | Number of trees (%) | Timber Volume (%) |
|---|---|---|
| *Quercus petraea* | 4,0 | 3,0 |
| *Quercus cerris* | 30,0 | 14,0 |
| *Carpinus betulus* | 4,0 | 0,9 |
| *Betula verrucosa* | 40,0 | 59,8 |
| *Populus tremula* | 4,0 | 4,9 |
| *Alnus glutinosa* | 4,0 | 3,4 |
| *Acer campestre* | 2,0 | 8,0 |
| *Acer tataricum* | 8,0 | 5,6 |
| *Pyrus pyraster* | 4,0 | 0,5 |
| Total | 100,0 | 100,0 |

| Number/ha | Volume/ha | Increment - Zv/ha | Diameter, Ds | Hight, Hs |
|---|---|---|---|---|
| Pcs. | $m^3$ | $m^3$/ha | cm | m |
| 1250 | 48,4 | 2,3 | 10,7 | 9,9 |

**Area,** Forest, 197 ha (49,5%), Not forest, 201 ha (50,5%), Total: 399 ha, Altitude: 400-800m

Table 3. Cluster Nº 2 - (Near village Vukotici)

| Species | Number of trees (%) | Timber Volume (%) |
|---|---|---|
| *Quercus petraea* | 9,1 | 3,2 |
| *Quercus cerris* | 27,3 | 13,1 |
| *Betula verrucosa* | 63,6 | 83,6 |
| Total | 100,0 | 100,0 |

| Number/ha | Volume/ha | Increment - Zv/ha | Diameter, Ds | Hight, Hs |
|---|---|---|---|---|
| Pcs. | $m^3$ | $m^3$/ha | cm | m |
| 1100 | 133,2 | 4,8 | 14,9 | 14,8 |

**Area,** Forest, 99 ha (24,6%), Not forest, 302 ha (75,4%), Total, 401 ha; Altitude, 800-1000m

Table 4. Cluster N° 3 - (locality Paljika)

| Species | Number of trees (%) | Timber Volume (%) |
|---|---|---|
| *Fagus moesiaca* | 81,7 | 79,0 |
| *Carpinus betulus* | 5,2 | 3,4 |
| *Betula verrucosa* | 12,3 | 9,6 |
| *Populus tremula* | 0,8 | 7,9 |
| Total | 100,0 | 100,0 |

| Number/ha | Volume/ha | Increment - Zv/ha | Diameter, Ds | Hight, Hs |
|---|---|---|---|---|
| Pcs. | $m^3$ | $m^3$/ha | cm | m |
| 1934 | 57,9 | 2,5 | 8,9 | 11,9 |

**Area,** Forest, 307 ha (75,3%), Not forest, 101 ha (24,7%), Total, 408 ha, Altitude, 1000-1200m

Table 5. Cluster N° 4 (under hill of Ceskovina)

| Species | Number of trees (%) | Timber Volume (%) |
|---|---|---|
| *Fagus moesiaca* | 100,0 | 100,0 |
| Total | 100,0 | 100,0 |

| Number/ha | Volume/ha | Increment - Zv/ha | Diameter, Ds | Hight, Hs |
|---|---|---|---|---|
| Pcs. | $m^3$ | $m^3$/ha | cm | m |
| 480 | 70,8 | 3,0 | 17,2 | 12,0 |

**Area,** Forest, 197 ha (48,6%), Not forest, 208 ha (51,4%), Total, 406 ha, Altitude, 1200-1400m

It can be concluded that the forest area within the basin covers around half of the study area (50 to 51% from 1977 to 2017). The forest area has been slightly increasing. The findings of this study are in line with observations of Nyssen *et al.* (2014) who stated that there is marked forest regrowth in the former Yugoslavia. Overall, forest cover has been naturally increasing in this region. In principle, the denser vegetation has led to higher water infiltration into the soil. The process of forest regrowth may be further accelerated by applying good silviculture measures and forest management practices.

Meadows, pastures and orchards cover the studied area from 40% to 43% (1977-2017), and this land cover type has been increasing in the period from 1987-1997, but again decreased on 40% in the recent years (2000-2017). According to Grimes *et al.* (2005), some marginal lands were cultivated again on the end of 20$^{th}$ century, as a consequence of the economic crisis in the region. This trend was also confirmed by our research on land use in the small Orahovacka Rijeka basin. On the other hand, for the period of 2000-2017, there has been stabilization of the land use changes (0 changes) in the area, both of forests and of arable and cultivated land. Detailed analysis of land use changes in the Orahovacka Rijeka basin are presented in Fig. 7.

According to Nyssen *et al.* (2014), land-use changes in Montenegro show that, on average, the area covered by dense vegetation increased from about 35 per cent in the early-20th century to 56 per cent at the end of 20$^{th}$ century. The wooded areas in the mountain region increased slightly. The share of agricultural land, represented by meadow and farmland, remained constant. This is similar with the findings of our research for the period 1977-1997.

The coefficient of vegetation cover, $S_2$, was calculated to be 0.71; the coefficient of the river basin planning, Xa, 0.48. Of the total river basin area, related to the river basin structure, in 2017, degraded forests are the most widespread plant forms (33.33%). The proportion is as follows: meadows (25.06%), well-constituted forests (17.95%), mountain pastures (10.59%), plough-lands (8.6%), orchards and vineyards (4.48%).

Our results for forest land were about 5 per cent less than those of Nyssen *et al.* (2014) because the Orahovacka Rijeka study area has a higher than average percentage of villages it is more densely populated than the other rural areas in the north Montenegro, being close to the Regional centre Bijelo Polje,

*Current erosion and the impact of land use on soil erosion intensity*

Over the last fifty years of the 20$^{th}$ century, anthropogenic factors have significantly increased the pressure on agricultural and forest land in Montenegro, degrading the vegetation cover which eventually results in serious degradation and loss of fertile soil.

The dominant erosion form in the study area is from surface runoff, but more severe forms of erosion, such as rills, gullies and ravines, occur also. 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 of Orahovacka Rijeka. Surface erosion has taken place in all soils on slopes, with the effect that this erosion is most pronounced on steep slopes with scarce or denuded vegetation cover. Similar results have been found for Brazilian watersheds, where higher slopes and poorly designed rural roads (Oliveira *et al.*, 2013; Silva *et al.*, 2014) have been the main reason for increasing surface erosion. Under the same conditions of soil, slope and vegetation cover, Avanzi (2009) reported that more concave slope can concentrate the runoff flow leading to great erosion rate.The results of the impact of land use changes on soil erosion intensity in the Orahovacka Rijeka river basin in five time profiles (years: 1977, 1987, 1997, 2007, 2017), calculated by the IntErO model, are presented in the Table 6 and Figs. 8 and 9.

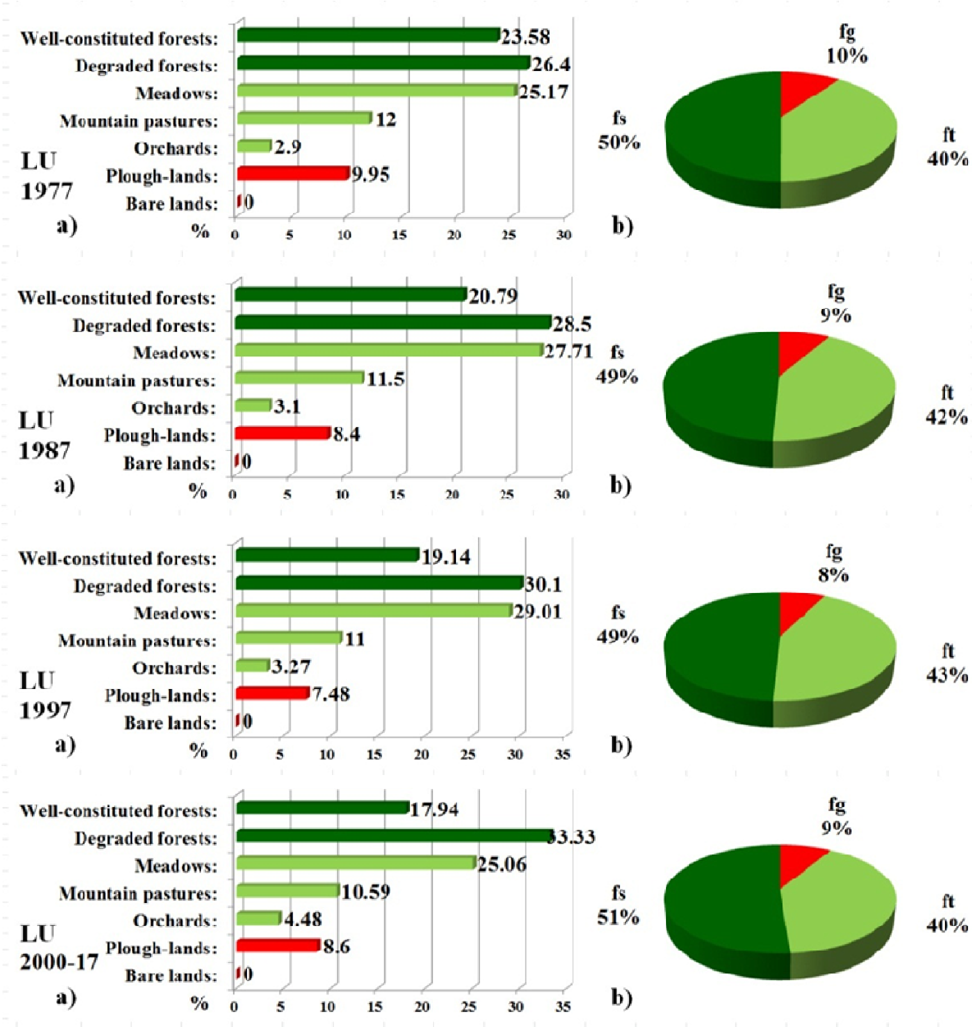


Fig. 7. Land use in the Orahovacka Rijeka river basin (1977, 1987, 1997, 2007, 2017)

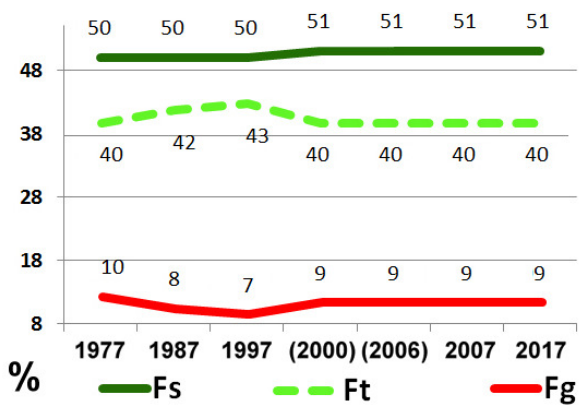


Fig. 8. Structure of the River basin: Fs – forest; Ft – grass; Fg – arable land

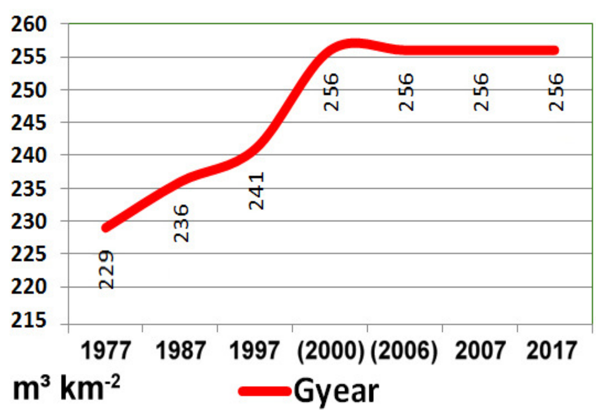


Fig. 9. Variability of soil erosion intensity due to vegetation covers changes: real soil losses (per km$^2$)

The graphic explained that the specific real soil losses (m$^3$ km$^{-2}$ year$^{-1}$) have increased from 229 m$^3$ year$^{-1}$ (1977) to 256 m$^3$ year$^{-1}$ (2017). According to our analysis, land use changes, specifically the change of the structure inside the arable land section (fg) influenced increase of the soil erosion intensity of 11% in the Orahovacka Rijeka River Basin.

On the other hand, the value of peak discharge, $Q_{max}$ (period from 1977 to 2017) remained almost the same: has decreased only by half percent (Table 6). Although we calculated just minor changes in the value of peak discharge, this is in principle in line with the findings of Nyssen *et al.* (2017) that in Montenegro, in the recent times, runoff has decreased due to an increase in vegetation cover.

Table 6. Part of the IntErO report for the Orahovacka Rijeka river basin (1977-2017)

| Input data | Abbrev. | 1977 | 1987 | 1997 | 2017 | Units of Measurement |
|---|---|---|---|---|---|---|
| River basin area | F | 11.4 | 11.4 | 11.4 | 11.4 | $km^2$ |
| The length of the watershed | O | 14.59 | 14.59 | 14.59 | 14.59 | km |
| Natural length of the main watercourse | Lv | 5.21 | 5.21 | 5.21 | 5.21 | km |
| The shortest distance from the spring to the mouth | Lm | 4.07 | 4.07 | 4.07 | 4.07 | km |
| Main watercourse with tributaries of class I and II | ΣL | 5.21 | 5.21 | 5.21 | 5.21 | km |
| River basin length by a series of parallel lines | Lb | 6.52 | 6.52 | 6.52 | 6.52 | km |
| The area of the larger river basin | Fv | 5.73 | 5.73 | 5.73 | 5.73 | $km^2$ |
| The area of the smaller river basin | Fm | 5.67 | 5.67 | 5.67 | 5.67 | $km^2$ |
| Altitude of the first contour line | h0 | 600 | 600 | 600 | 600 | m |
| Equidistance | Δh | 100 | 100 | 100 | 100 | m |
| The lowest river basin elevation | Hmin | 544 | 544 | 544 | 544 | m |
| The highest river basin elevation | Hmax | 1331 | 1331 | 1331 | 1331 | m |
| Portion of the basin with very permeable rocks | Fp | 0 | 0 | 0 | 0 | |
| Portion of the basin with medium permeable rocks | Fpp | 0.08 | 0.08 | 0.08 | 0.08 | |
| Portion of the basin with low permeability rocks | Fo | 0.92 | 0.92 | 0.92 | 0.92 | |
| Portion of the river basin which is forested | Fs | 0.5 | 0.5 | 0.5 | 0.51 | |
| Grass, meadows, pastures and orchards | Ft | 0.4 | 0.42 | 0.43 | 0.4 | |
| Plough-land, ground without grass vegetation | Fg | 0.1 | 0.08 | 0.07 | 0.09 | |
| The volume of the torrent rain | Hb | 157.6 | 157.6 | 157.6 | 157.6 | mm |
| Incidence | Up | 100 | 100 | 100 | 100 | years |
| Average annual air temperature | t0 | 8.9 | 8.9 | 8.9 | 8.9 | °C |
| Average annual precipitation | Hyear | 873.7 | 873.7 | 873.7 | 873.7 | mm |
| Types of soil and related types | Y | 1.1 | 1.1 | 1.1 | 1.1 | |
| Coefficient of the river basin planning | Xa | 0.45 | 0.46 | 0.46 | 048 | |
| Numeral equivalents of visible erosion process | Φ | 0.3 | 0.3 | 0.3 | 0.3 | |
| **Results:** | | | | | | |
| Coefficient of the river basin form | A | 0.55 | 0.55 | 0.55 | 0.55 | |
| Coefficient of watershed development | M | 0.44 | 0.44 | 0.44 | 0.44 | |
| Average river basin width | B | 1.75 | 1.75 | 1.75 | 1.75 | km |
| (A)symmetry of the river basin | A | 0.01 | 0.01 | 0.01 | 0.01 | |
| Density of the river network within the basin | G | 0.46 | 0.46 | 0.46 | 0.46 | |
| Coefficient of the river basin tortuousness | K | 1.28 | 1.28 | 1.28 | 1.28 | |
| Average river basin altitude | Hsr | 863.47 | 863.47 | 863.47 | 863.47 | m |
| Average elevation difference of the river basin | D | 319.47 | 319.47 | 319.47 | 319.47 | m |
| Average river basin decline | Isr | 32.55 | 32.55 | 32.55 | 32.55 | % |
| The height of the local erosion base of the basin | Hleb | 787 | 787 | 787 | 787 | m |
| Erosion energy of the river basin's relief | Er | 136.33 | 136.33 | 136 | 136 | |
| Coefficient of the region's permeability | S1 | 0.98 | 0.98 | 0.98 | 0.98 | |
| Coefficient of the vegetation cover | S2 | 0.72 | 0.72 | 0.72 | 0.71 | |
| Water retention inflow | W | 1.7097 | 1.7097 | 1.7097 | 1.7097 | m |
| Energetic potential of water flow during torrents | 2gDF^½ | 267.34 | 267.34 | 267.34 | 267.34 | m km s |
| Peak discharge from the river basin | Qmax | 175.99 | 174.54 | 174.53 | 174.31 | $m^3 s^{-1}$ |
| Temperature coefficient of the region | T | 0.99 | 0.99 | 0.99 | 0.99 | |
| Coefficient of the river basin erosion | Z | 0.444 | 0.454 | 0.46 | 0.478 | |
| Production of erosion material in the river basin | Wyear | 9208 | 9510 | 9705 | 10290 | $m^3 year^{-1}$ |
| Coefficient of the deposit retention | Ru | 0.284 | 0.284 | 0.284 | 0.284 | |
| Real soil losses | Gyear | 2614 | 2700 | 2755 | 2921 | $m^3 year^{-1}$ |
| Real soil losses per $km^2$ | Gyear | 229 | 236 | 241 | 256 | $m^3 km^{-2}$ |

## Conclusions

The most significant factors that have influenced erosion processes within the Orahovacka Rijeka river basin are the area's climate, relief, geological substrate and pedological composition, the condition of the vegetation cover and land use.

We studied how the past land use variants (for 40 years from 1977 to 2017) influenced the soil erosion process and runoff in the Orahovacka Rijeka basin in Montenegro, looking for solutions as to how these findings could be used to modify our policies based on prediction or optimization of the future land and water management options in the wider regions of the country.

The migration of rural population to towns and the resulting abandonment of farm land in the recent years resulted in slight increase of forested area. Degraded forests are the most widespread form (33%) of land use. Further proportions are as follows: meadows (25.06%), well-constituted forests (17.95%), mountain pastures (10.59%), plough-lands (8.6%), and orchards (4.48%). Areas under the forests has increased from 50% (1977) to 51% (2017) of the total river basin area. This vegetation of more than half of the total area keeps high infiltration rates. The process of forest regrowth may be further accelerated by changing rural demography, applying good silviculture measures and forest management practices, transforming the areas of degraded forests into the forest of good cover.

For the current state of land use, calculated peak discharge for the Orahovacka Rijeka was 174-175 $m^3 s^{-1}$ (the incidence of 100 years) and there is a possibility for large flood waves to appear in the studied basin. Real soil losses, $G_{year}$, were calculated on 2614-2921 $m^3$ $year^{-1}$, specific 229-256 $m^3$ $km^{-2}$ $god^{-1}$ (1977-2017). The value of Z coefficient range from 0.444 to 0.478 and 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.

According to our analysis the land use changes in the last 40 years influenced the increase of the soil erosion intensity for 11% in the study watershed, which is in line with the findings of Nyssen *et al.* (2014) showing that in Montenegro, recent runoff decreases are due to vegetation increase. This result can be considered as a good message because of slight increasing - stabilisation of the vegetation cover in the study area, but it is also important to focus on the reasons of this feedback. In other words, changing in rural demography can be a hazard if the main reason is decreasing rural population due to migration which can leads to various problems in the towns.

Although the research was conducted on the small Orahovacka Rijeka basin of the Polimlje region of Montenegro, the results of this study are important as they confirm the general findings for the territory of Montenegro, providing new specific data with the very detailed analysis, in relation to the soil erosion processes and the impact of land use changes on soil erosion intensity and runoff in the north of Montenegro.

This study further confirmed the findings of Kostadinov *et al*. (2014), Tazioli (2009), as well as Spalevic (2011), which leads to the conclusion that the IntErO model is a useful tool for researchers in calculation of runoff and sediment yield at the level of the river basins of Southeast Europe and areas with physical characteristics similar to the Polimlje Region of Montenegro.

The Orahovacka Rijeka river basin of the Polimlje Region in Montenegro, but also the nearby river basins will, according to our analysis, become more vulnerable in the future and thus the eco-environmental system will become more unstable. Further studies should be focused on the detailed analysis of the trends of land use changes, closely following responses of soil erosion to the changed land use structure, effects of plant-and-soil interaction on soil erosion and sediment dynamics and also the interactions between socio-economic problems and soil erosion process.

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