10.7251/AGSY1303054S

THE IMPACT OF LAND USE ON SOIL EROSION IN THE RIVER BASIN BOLJANSKA RIJEKA IN MONTENEGRO

Velibor SPALEVIĆ[1]*, Jan NYSSEN[2], Milic CUROVIC[1], Tom LENAERTS[2], Annelies KERCKHOF[2], Klaas ANNYS[2], Jeroen VAN DEN BRANDEN[2], Amaury FRANKL[1]

[1]University of Montenegro, Biotechnical Faculty, Podgorica, Montenegro
[2]Ghent University, Department of Geography, Ghent, Belgium
(Corresponding author: velibor.spalevic@gmail.com)

Abstract

Soil erosion is acknowledged as a major environmental problem, threatening sustainable livelihoods around the world. Inappropriate land use and land management is often viewed as main cause of accelerated erosion rates. Therefore, modelling soil erosion rates under various land use and climate conditions is key to understand the impact of future land management and climate change on land degradation. For the Boljanska Rijeka River Basin (Polimlje, Montenegro), we studied soil erosion processes, using a series of data that are reflecting variations in land use over a period of four decades (1970-2013). The computer-graphic IntErO model was used to calculate soil erosion intensity, taking data of Forest Management Plans, Cadastre, Landsat images and Statistical Yearbooks into account. It was concluded that the condition of the vegetation cover and the land use influenced the development of erosion processes in the river basin. For the current state of land use, calculated maximal outflow from the river basin is 212 $m^3 s^{-1}$ and the net soil loss is 8644 m^3 $year^{-1}$. This indicates that the river basin belongs in „Destruction Category V", according to the classification system of Gavrilovic. The strength of the erosion process is medium, and according to the erosion type, it is mixed erosion. Change of the land use in structure for the period of four decades (1970-2013), in the studied river basin, decreased the soil erosion intensity by 3.95%.

Key words: *Soil erosion rates, Runoff, Land use, Modelling, Prediction, IntErO model.*

Introduction

Erosion is responsible for large soil losses. According to Poesen *et al.* (2003) in this part of Europe, erosion has led to the formation of extensive degraded areas called badlands, in which high rates of soil loss is observed (Mathys *et al*. 2003).

According to Spalevic (2011), Kostadinov *et al.* (2006), Lazarevic (1996) water erosion has affected 13,135 km^2 or 95% of the total territory of Montenegro (13,812 km^2). Erosion caused by water is dominant in the terrains with high slopes due to complex physical and geographical conditions paired with reckless logging (Spalevic *et al*. 2012).

The exploitation of forests and the irrational use of land caused a change in land use structure (Nyssen *et al.*, 2012), and the quality of vegetation cover in the studied river. The soil and geological substrate are exposed to the impact of various agents, particularly water, temperature and gravity. A field survey shows that in some places, some ridges, gullies and ravines have appeared; at some highlands sandbanks are present.

All these facts obtained in the process of the field survey led the authors to analyse the impact of land use on soil erosion intensity in this area using a computer-graphic method.

Material and methods

The study was conducted in the area of the river basin of Boljanska Rijeka, a right-hand tributary of the river Lim, which lies on the slopes of Kurilo (1314m) on the North, Krstac (910m) and Macino brdo (1076) from the South (Figure 1). The river basin of Boljanska Rijeka encompasses an area of 27.5 km^2. It is part of the natural entity of the Polimlje region (North-East of Montenegro). The natural length of the main watercourse, Lv, is 6.5 km. The shortest distance between the fountainhead and the mouth, Lm, is 6 km. The total length of the main watercourse, with tributaries of I and II class, ΣL, is 8.66 km.

Fieldwork was undertaken to collect detailed information on the intensity and the 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 and the density of erosion rills.

We drew on the earlier pedological work of Fustic and Djuretic (2000), who analysed the physical and chemical properties of all the Montenegrin soils, including those in the study area of Boljanska Rijeka. Furthermore, some pedological profiles had been reopened, and soil samples were taken for physical and chemical analysis. The granulometric 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.

Polimlje: 43.245703 N, 19.580383 E (North); 42.508046 N, 19.905853 E (South); 43.148092 N, 19.485626 E (West); 42.963960 N, 20.120087 E (East).

Figure 1: Study area

The 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.

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 predictive model for the evaluation of different management scenarios for the protection of soils. Field measurements of erosion and sedimentation using classical techniques is time-consuming and expensive (Bujan *et al*. 2000). The modelling of the erosion process has progressed rapidly, and a variety of models have been developed to predict both the runoff and soil loss (Zhang *et al.* 1996).

Most of the methodologies remained at the qualitative (descriptive) level, relying on empirical evidence and expert subjective evaluation of the conditions. In the South-Eastern European Region two methodologies have achieved the required level of standardization of research procedures to minimize subjective errors of the researchers, which allows obtaining uniform results, tracking the state of changes in erosion intensity over a period of time.

The first method is the "*Soil Loss Equation*" of the U.S. Soil Conservation Services, further improved, now known as USLE (*Universal Soil Loss Equation*). Another method is the "*Erosion Potential Method - EPM*", created, developed, and calibrated in Yugoslavia (Gavrilovic, 1972).

Both of these methods are standard for use in agriculture and water management, according to its primary purpose, but it should be noted that the accuracy of the USLE method ends for the surfaces with the slope of less than 7^0 as it is developed for determining of erosion processes for agricultural production. “*Erosion Potential Method*” covers a wide range of soil erosion intensities.

According to previous experience, and verifications (Spalevic, 2011, 2012, 2013) the most reliable method for determining the sediment yields and the intensity of the erosion processes for the area of North of Montenegro is the *Erosion Potential Method.*.

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 EPM was the most suitable on catchment level for the watershed management needs in this Region.

The use of computer-graphics in research on runoff and the intensity of soil erosion have been demonstrated in Montenegro, specifically in the Region of Polimlje (Spalevic *et al.* 2013, 2012, 2011, 2007, 2004, 2003, 2001, 2000, 2000a, 1999, 1999a), Fustic and Spalevic (2000). That approach was used in the research on the river basin of Boljanska Rijeka. We used the **Int**ensity of **Er**osion and **O**utflow (IntErO) program package (Spalevic, 2011) to obtain data on forecasts of maximum runoff from the basin and soil erosion intensity. EPM is embedded in the algorithm of this computer-graphic method.

Results and discussion

Physical-geographical characteristics and erosion factors

The river basin of Boljanska Rijeka stretches from its inflow to Lim (H_{min}, is 550 m) to the tops of the Kofiljaca, where the H_{max} is 1314 m. There is a flat area in and around the village of Rasova, mild slopes around the village Boljana and steep slopes in the upper part of the river basin on the slopes of Kofiljaca. The average river basin decline, Isr, is 41.6% and indicates that in the river basin prevail very steep slopes. The average river basin altitude, Hsr, is 736.33 m; the average elevation difference of the river basin, D, is 186.33 m.

Figure 2: Details from the River basin: Zminjica (left), Boljanska River (right)

Climatic characteristics

The area is characterised by dry summers; rainy autumns and springs; and cold winters. The absolute maximum air temperature is 39.2^{O}C. Winters are severe, so much so that negative temperatures can fall to a minimum of -27.6^{O}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, h_b, is 84.7 mm. The average annual air temperature, t_0, is 8.9°C. The average annual precipitation, H_{year}, is 873 mm.

The geological structure of the area

In the structural-tectonic sense, the studied 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 and Quaternary.

The coefficient of the region's permeability, S1, is calculated on 0.96. The structure, according to the permeable products from rocks is presented in the Figure 3.

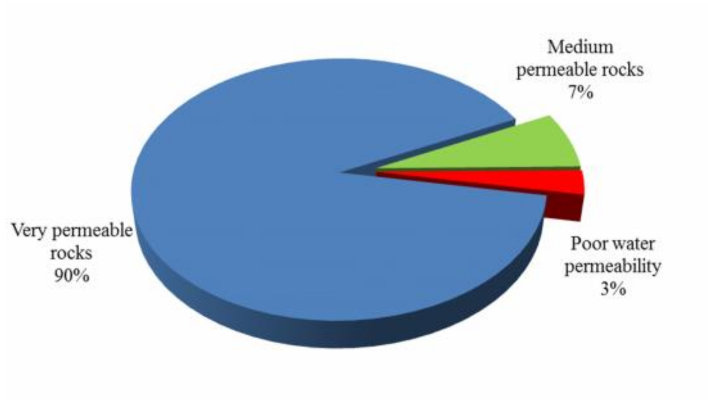

Figure 3: Structure of the Boljanska River basin according to the permeable products from rocks

Soil characteristics of the area

Going from the inflow of the Boljanska Rijeka past Lim to the surrounding mountainous terrain, the most common soil types are Brown district (acid) soils (84%) and Brown eutric soils (15%); close to the inflow of Boljanska River to Lim, Alluvial-deluvial soils.

Vegetation and Land use

The studied area is located in Dinaridi Province of the Middle-Southern-East European mountainous biogeographical region. The dominant type of vegetation in the studied river basin is forests accounting for two thirds of the total vegetation cover.

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

On the vertical profile, River basin of Boljanska river is differentiated from the following forest communities: (1) *Quercetum petraeae-cerridis*, Lak. Mostly in the southern exposure of the valleys of the main watercourse, and the lower parts of its tributaries; (2) *Quercetum petraeae montenegrinum*, Lak. On the hilly parts of the river basin; (3) *Fagetum montanum* differentiated into several associations (Curovic *et al*. 2011) and (4) *Abieti - Fagetum moesiacae* Blec and Lak.

Most of the river basin is covered with low beech forests (*Fagetum montanum*) and forests of Sessile oak and Turkish oak (*Quercetum petraeae-cerridis*). On the southern exposures and lower altitudes there are forests of Sessile oak and Turkish oak (*Quercetum petraeae-cerridis*). A narrow belt near the river in the lower part of the river basin is covered with hygrophilic forest (*Alnetea glutinosae, Salicetea herbacea*). At the higher parts of the basin there are mixed of broadleaves and deciduous tree species (*Abieti - Fagetum moesiacae*). In last decades climate change on forest ecosystems affected moving of the vegetation vertical layout belts (Curovic and Spalevic, 2010).

The coefficient of the vegetation cover, S_2, is calculated on 0.7. The coefficient of the river basin planning, X_a, is 0.5. Of the total river basin area, related to the river basin structure, degraded forests are the most widespread form (40.67%). Further proportion is as follows: well-constituted forests (21.9%), arable land - plough-lands (14.07%), meadows (12.35%), grassland (6.76%), and orchards (4.25%). The structure of the river basin of Boljanska Rijeka, according to the land use is presented in Figure 4.

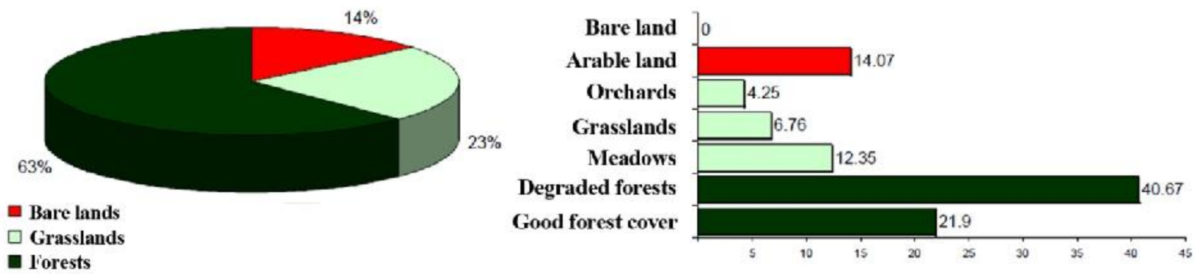

Figure 4: Land use in the river basin of Boljanska Rijeka (year 2013)

Characteristics of the basin regarding issues of soil erosion and runoff

The dominant erosion form in this area is 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. Surface erosion has taken place in all the soils on the slopes, with the effect that this erosion is most pronounced on the steep slopes with scarce or denuded vegetation cover.

Figure 7: Detail from the basin - Kurilo

We used the software IntErO for calculation of the soil erosion intensity and the maximum outflow.

Coefficient of the river basin form, A, is calculated on 0.95. Coefficient of the watershed development, m, is 0.34 and average river basin width, B, is 2.12 km. (A)symmetry of the river basin, a, is calculated on 0.69 and indicates that there is a possibility for large flood waves to appear in the river basin.

Density of the river basin network, G, is calculated on 0.32 and indicates there is low density of the hydrographic network. The height of the local erosion base of the river basin, Hleb, is 764 m. Coefficient of the erosion energy of the river basin’s relief, Er, is 106.28.

Coefficient of the river basin erosion, Z, is 0.537. The strength of the erosion process is medium, and according to the erosion type, it is mixed erosion.

Production of erosion material in the river basin, Wgod, is calculated on 29484 m^3 $year^{-1}$; Coefficient of the deposit retention, Ru, on 0.293. For the current state of land use, calculated maximal outflow from the river basin is 212 m^3s^{-1}. Real soil losses, G year, are calculated on 8644 m^3 $year^{-1}$; and the specific real soil losses on 315 m^3 km^{-2} $year^{-1}$.

The impact of Land use on Soil erosion

Using a series of data of Forest Management Plans, Cadastre, Landsat images and Statistical Yearbooks that are characterizing variations in land use over the period of four decades (1970-2013) it is concluded that:

- Area under forests is prevailing covering around two thirds of the area; meadows, pastures and orchards covers around quarter of the studied river basin; ploughed land and ground without grass vegetation are decreasing from 16% (1970) to 14% (2013). The land use changes are presented on Figure 8.

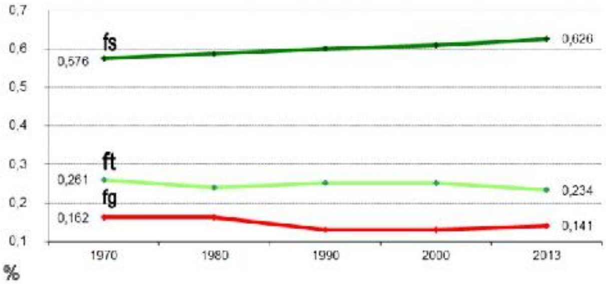

Figure 8: Land use (period 1970-2013)

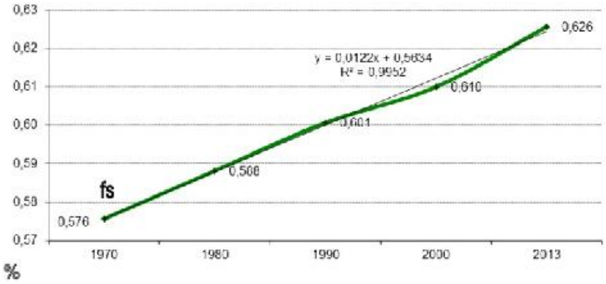

Figure 9: Forests (fs)

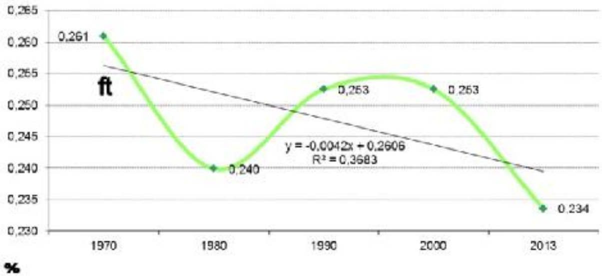

Figure 10: Orchards and meadows (ft)

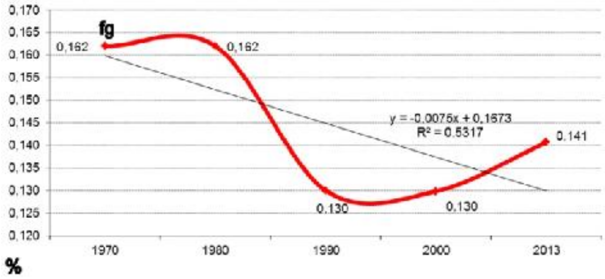

Figure 11: Bare lands, & Plough-lands (fg)

- Increase of areas under the forests over the period of time is presented on Figure 9.

-Decrease of the areas under the grassland is presented on Figure 10.

-The areas under bare lands & plough-lands on figure 11.

Figure 12. Stanica Scekic showing the change of land use: from wheat (1980) to meadows (2010).

The impact of land use on soil erosion intensity over the period of four decades in the Boljanska river basin is presented in the Figures 13 – 16.

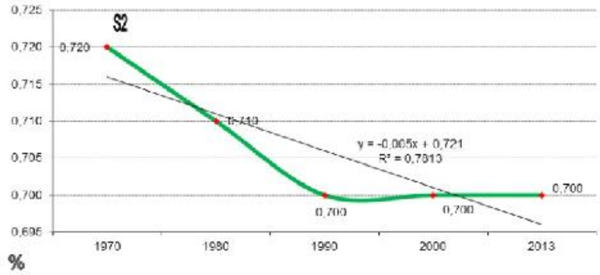

Figure 13. Vegetation cover coefficient

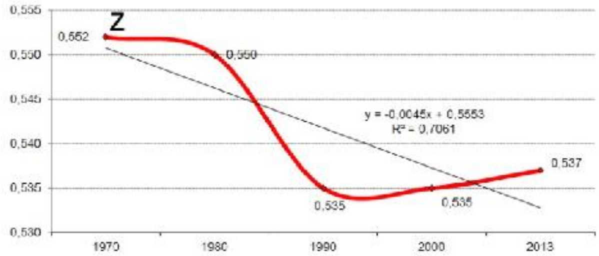

Figure 14. River basin erosion coefficient

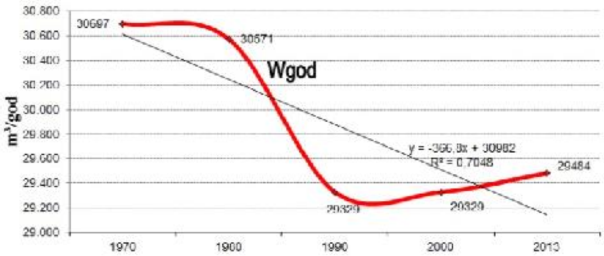

Figure 15. Production of erosion material in the basin

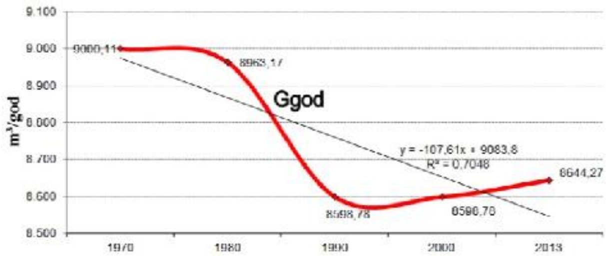

Figure 16. Real soil losses

Those graphics explained that the value of the Vegetation cover coefficient (S2) stabilised on 0.7 after the decade 1990. The value of the River basin erosion coefficient (Figure 14) is decreasing from 0.552 (1970) to 0.537 (2013). Production of erosion material (Figure 15) over the period of four decades in the river basin is also decreasing from 30697 m^3 $year^{-1}$ (1970) to 29484 m^3 $year^{-1}$ (2013). Real soil losses for the river basin per year (Figure 16) are decreased for 356 m^3 $year^{-1}$, from 9000 m^3 $year^{-1}$ (1970) to 8644 m^3 $year^{-1}$ (2013).

Conclusion

Many factors have influenced the erosion processes in the territory of the river basin of Boljanska Rijeka. The most significant factors are the area's climate, relief, geological substrate and pedological composition, as well as the condition of the vegetation cover and the land use.

Maximal outflow (appearance of 100 years) from the river basin, Q_{max}, is 212 m^3 s^{-1} and is suggesting the possibility of a large flood. The strength of the erosion process is medium, and the erosion type is mixed erosion. The calculated soil losses were 8644 m^3/year (315 m^3/km^2/year).

Change of the land use in structure for the period of four decades (1970-2013), in the studied river basin, according to our analyses, decreased the soil erosion intensity for 3.95%.

Acknowledgement

This research was funded by the Ministry of Science of Montenegro.

References

Blinkov I. and Kostadinov S. (2010): Applicability of various erosion risk assessment methods for engineering purposes, BALWOIS 2010 Conference - Ohrid, Republic of Macedonia. 25 - 29 May 2010.

Bujan, A., Santanatoglia, O. J., Chagas, C., Massobrio, M., Castiglioni,M., Yanez, M. S., (2000): Preliminary study on the use of the 137Cs method for soil erosion investigation in the Pampean region of Argentina. Acta Geologica Hispanica, 35(3–4), 271–277.

Curovic, M. Stesevic, D., Medarevic, M., Cvjeticanin, R., Pantic, D. and Spalevic, V. (2011): Ecological and structural characteristics of monodominant montane beech forests in the National park Biogradska Gora, Montenegro. Archives of Biological Sciences 63 (2), 429-440.

Curovic, M. and Spalevic, V. (2010): Climate changes impacts on forests in Montenegromitigation and adaptation; International Conference – Forest ecosystems and Climate changes; March 9-10th Belgrade, Serbia, p.283-287, IUFRO; EFI; Institute of forestry;, Beograd.

Gavrilovic, S. (1972): Inzenjering o bujicnim tokovima i eroziji. Izgradnja. Beograd.

Fustic B. and Spalevic V. (2000): Characteristics of erosion processes in the river basin of Daspic river. Agriculture and Forestry, Vol. 46. (1-2): 5-17, Podgorica.

Fustic, B., and Djuretic, G. (2000): Soils of Montenegro. Biotechnical institute, University of Montenegro.

Kostadinov S., Zlatic M., Dragovic N., Gavrilovic Z. (2006): Soil Erosion in Serbia and Montenegro, Soil Erosion in Europe, ISBN13 978-0-470-85910-0; UDK 631.4; p.p. 271-277; Editors: John Bordman and Jean Poesen; John Wiley &Sons, Ltd; London

Lazarevic, R. (1996): Erozija u Crnoj Gori. Erozija, strucno-inf. bilten, br.23. Beograd.

Mathys, N., Brochot, S., Meunier, M., Richard, D., 2003. Erosion quantification in the small marly experimental catchments of Draix (Alpes de Haute Provence, France). Calibration of the ETC rainfall-runoff-erosion model. Catena, 50: 527-548.

Nyssen, J., Van den Branden, J., Spalevic, V., Frankl, A., Van de Velde, L., Curovic, M. and Billi, P. (2012): Twentieth century land resilience in Montenegro and consequent hydrological response. Land Degradation & Development. Article first published online: 7 MAR 2012 (Online Version of Record published before inclusion in an issue) DOI: 10.1002/ldr.2143.

Poesen, J., Nachtergaele, J., Verstraeten, G., Valentin, C., 2003. Gully erosion and environmental change: Importance and research needs. Catena, 50: 91-133.

Spalevic, V., Šimunić, I., Vukelić-Šutoska, M., Uzen, N., Čurović, M. (2013): Prediction of the soil erosion intensity from the river basin Navotinski, Polimlje (Northeast Montenegro). Agriculture and Forestry, Vol. 59. Issue 2: 9-20, 2013, Podgorica. ISSN 0554-5579 (Printed), ISSN 1800-9492 (Online).

Spalevic, V., Mahoney, W., Đurović, N., Üzen, N., Čurović, M. (2012): Calculation of soil erosion intensity and maximum outflow from the Rovacki river basin, Montenegro. Agriculture & Forestry, Vol. 58. Issue 3: 7-21, 2012, Podgorica. ISSN 0554-5579 (Printed) ISSN 1800-9492 (Online).

Spalevic, V. (2011): Impact of land use on runoff and soil erosion in Polimlje. Doctoral thesis; p 1-260. Faculty of Agriculture of the University of Belgrade, Serbia.

Spalevic, V., Čurović, M., Povilaitis, A. (2007): Conditions of soil erosion in the Komarača river basin, North-East of Montenegro. International Conference "Erosion and Torrent Control as a factor in sustainable River Basin management". Belgrade.

Spalevic, V., Čurović, M., Povilaitis, A., Radusinović, S. (2004): Estimate of Maximum Outflow and Soil Erosion in the Biogradska River Basin. Monographs, No1, Biodiversity of the Biogradska Gora National Park; Editors: Pešić, V., Karaman, G., Spalevic, V., Jovović, Z., Langurov, M. Department of Biology of the University of Montenegro; Podgorica, p. 1-20.

Spalevic, V., Seker, G, Fuštić, B, Šekularac, Ristić R. (2003): Conditions of Erosion of Soil in the Drainage Basin of the Crepulja - Lucka River; page 287-292. International conference, "Natural and Socioeconomic effects of Erosion Control in Mountainous Regions", Banja Vrujci, Srbija, Faculty of Forestry, Belgrade University, World Association of Soil and Water Conservation.

Spalevic V., Fuštić B., Šoškić S., Ristić R. (2001): The estimate of maximum outflow and soil erosion intensity in the Vinicka river basin with application of computer graphic methods. Agriculture and Forestry, Vol 47. (3-4): 95-104, Podgorica.

Spalevic V., Fuštić B., Jovović Z., Čurović M., Spalevic B., Popović V. (2000): Characteristics of erosion processes and proposal of land reclamation measures in the drainage basin of the Šekularska river. Agriculture and Forestry, Vol. 46 (3-4): 2-18, Podgorica.

Spalevic V., Dlabač A., Spalevic B., Fuštić B., Popović V. (2000): Application of computer - graphic methods in the research of runoff and intensity of ground erosion - I program "River basins". Agriculture and Forestry, Vol. 46. (1-2): 19-36, Podgorica.

Spalevic, V. (1999): Application of computer-graphic methods in the studies of draining out and intensities of ground erosion in the Berane valley. Master thesis, p 1-135. Faculty of Agriculture of the University of Belgrade, Serbia.

Spalevic, V., Dubak, D., Fuštić, B., Jovović, Z., Ristić, R. (1999): The Estimate of the Maximum Outflow and Soil Erosion Intensity in the Kaludra River Basin. Acta Agriculturae Serbica, Vol. IV, 8 (1999) 79-89, Čačak, Serbia.

Zhang, X. C., Nearing, M. A., Risse, L. M., & McGregor, K. C. (1996): Evaluation of WEPP runoff and soil loss predictions using natural runoff plot data. Transactions of the ASAE, 39(3), 855–863.

Zivaljevic M. (1989): Tumac Geoloske karte SR Crne Gore, 1:200 000; Posebna izdanja Geoloskog glasnika, Knjiga VIII, Titograd.