Rodrigues Neto, M.R.; Musselli, D.G.; Lense, G.H.E.; Servidoni, L.E.; Stefanidis, S.; Spalevic, V.; Mincato, R.L. (2022). Soil loss modelling by the IntErO model - Erosion Potential Method in the Machado River Watershed, Minas Gerais, Brazil. Agriculture and Forestry, 68 (2): 7-21. doi:10.17707/AgricultForest.68.2.01

DOI: 10.17707/AgricultForest.68.2.01

Manoel Ribeiro RODRIGUES NETO[1], Denis Giovanni MUSSELLI[1], Guilherme Henrique Expedito LENSE[1], Lucas Emanuel SERVIDONI[1], Stefanos STEFANIDIS[2], Velibor SPALEVIC[3] and Ronaldo Luiz MINCATO[1]

SOIL LOSS MODELLING BY THE IntErO MODEL - EROSION POTENTIAL METHOD IN THE MACHADO RIVER BASIN, MINAS GERAIS, BRAZIL

SUMMARY

Water erosion has radically affected the productive capacity of soils, especially in regions with a tropical climate, causing environmental and social damage, such as reduced agricultural productivity and siltation of water bodies. The objective of this research was to estimate soil losses with using the IntErO model - Erosion Potential Method in the River Machado Watershed (MRW), South Minas Gerais State (Brazil), with the idea to identify areas of increased soil losses due to water erosion, contributing with the research activities to the environmental planning in order to prevent land degradation. The Machado River basin was selected as study area because it is an important Sustainable Use Conservation Unit in Minas Gerais, which has abundant water resources, rich biodiversity, and intensive agricultural production. The estimated soil losses for the year 2020 were calculated, using the IntErO model - Erosion Potential Method, in a Geographic Information System (GIS) environment. The MRW presented an average soil loss of 18.2 Mg ha^{-1} yr^{-1}, and a total of about 2 million tons per year. In about 85% of the watershed, soil losses were greater than the tolerable limits, what leads to the conclusion that there is a need to adopt a comprehensive soil conservation management plan to reduce water erosion. The highest average soil losses occurred in areas of exposed soil as well as sporadic agricultural and pasture, and are concentrated in the southern sector of the studied area. The results obtained can support the environmental planning aimed at the conservationist use of the soil in the MRW.

Key words: Soil Conservation; Soil Erosion; IntErO model; EPM; Environmental Planning; GIS; Nature Conservation; Brazil.

---

[1] Manoel Ribeiro Rodrigues Neto, Denis Giovanni Musselli, Guilherme Henrique Expedito Lense, Lucas Emanuel Servidoni, Ronaldo Luiz Mincato (corresponding author: ronaldo.mincato@unifal-mg.edu.br), Federal University of Alfenas, UNIFAL-MG, Alfenas, Minas Gerais, BRAZIL;

[2] Stefanos Stefanidis, Laboratory of Mountainous Water Management and Control, Faculty of Forestry and Natural Environment, Aristotle University of Thessaloniki, Thessaloniki, GREECE;

[3] Velibor Spalevic, University of Montenegro, Biotechnical Faculty, Podgorica, MONTENEGRO;

Notes: The authors declare that they have no conflicts of interest. Authorship Form signed online.

Recieved:09/04/2022 *Accepted:12/06/2022*

INTRODUCTION

Soil erosion is one of the most widespread and a major environmental threat which decreases agricultural productivity and affects water quality (Artemyeva *et al.*, 2021; Kavian *et al.*, 2018; Kavian *et al.*, 2017; Spalevic *et al.*, 2017; Khaledi Darvishan *et al.*, 2016; Mohammadi and Kavian, 2015; Spalevic *et al.*, 2013; Nearing *et al.*, 2005). Water erosion has drastically affected the productive capacity of soils, especially in tropical regions, due to the large volume of rainfall (Panachuki *et al.*, 2006; Santos *et al.*, 2010). The four basic factors that regulate water erosion rates are topography, climate, soil types and characteristics, and land cover (Panagos *et al.*, 2015). The erosion rates are generally higher on terrains with longer and steeper slopes due to increased runoff volume and velocity (Tavares *et al.*, 2021).

Erosive processes accelerated or intensified by human activities (Bigarella, 2007) cause damage to the environment and society, both in places where they occur (in loco) and in nearby or distant areas, such as reduction or even closure of agricultural production, the loss of soil fertility and siltation of water bodies (Guerra and Mendonça, 2020).

Over the past 50 years, several water erosion estimation models have been developed and improved (Lovric and Tosic, 2018, Santana *et al.*, 2021). These models are based on mathematical equations that express the relationship between environmental parameters and allow the estimation of soil losses with an acceptable level of accuracy (Stefanidis and Stathis, 2018). In addition, the association of modelling with Geographic Information Systems allows the spatialization of results, facilitating the implementation of actions in the field of soil conservation management (Imamoglu and Dengiz, 2017).

The Erosion Potential Method (EPM) is a model for estimating water erosion, based on simple and low-cost obtaining parameters (Gavrilovic, 1962). EPM has been widely used in the South East European regions, Italy, the Middle East, and North Africa (El Mouatassime *et al.*, 2019; Stefanidis and Stathis, 2018; Nikolic *et al.*, 2018; Darvishan *et al.*, 2017; Spalevic *et al.*, 2017; Dragicevic *et al.*, 2017; 2016;). It has also been recognized as the most quantitative of all the semi-quantitative models (De Vente *et al.*, 2005). Noteworthy studies comparing EPM erosion model output with field measurements shows that give satisfactory results (Tazioli, 2009; Efthimiou *et al.*, 2016). More recently, the IntErO model (www.geasci.org/IntErO) – EPM method have been applied to tropical conditions in Brazil, giving accurate results (Sakuno *et al.*, 2020; Tavares *et al.*, 2019; Lense *et al.*, 2019; Silva *et al.*, 2014).

In this scenario, the objective of the work was to estimate the soil loss rates by using the IntErO model - Erosion Potential Method in the Environmental Protection Area (APA) of the Rio Machado Watershed, southern of Minas Gerais State, to identify the areas with environmentally unsustainable soil loss due to water erosion and contribute to environmental planning and soil and water conservation policies. The Machado River Watershed was selected as the study area because it is an important Conservation Unit in the State of Minas Gerais, with abundant water resources and rich biodiversity, and, on the other hand, widely used by the agricultural sector.

MATERIAL AND METHODS

Study area. The Machado River Watershed (MRW) is a Conservation Unit (protected area) in the State of Minas Gerais, south-eastern Brazil. It has an area of 101,600 ha and covers eleven municipalities of southern of Minas Gerais State (Figure 1). The area is under the anthropogenic influence in certain degree, being endowed with abiotic, biotic, aesthetic, or cultural attributes. Its basic objectives are the protection of biodiversity and maintaining the sustainable use of natural resources (IEF, 2021).

The Machado River is the main watercourse of the watershed, having 112.2 km of extension and an expressive altimetric gradient between its high and medium course. Its main tributaries are the Machadinho do Campo and Machadinho streams, on the right bank, and, on the left bank, the Jacutinga and Conceição streams (Latuf *et al*., 2019). The Machado River watershed is part of the Rio Grande Watershed and has the Furnas Reservoir as its base level (Justino *et al*., 2019).

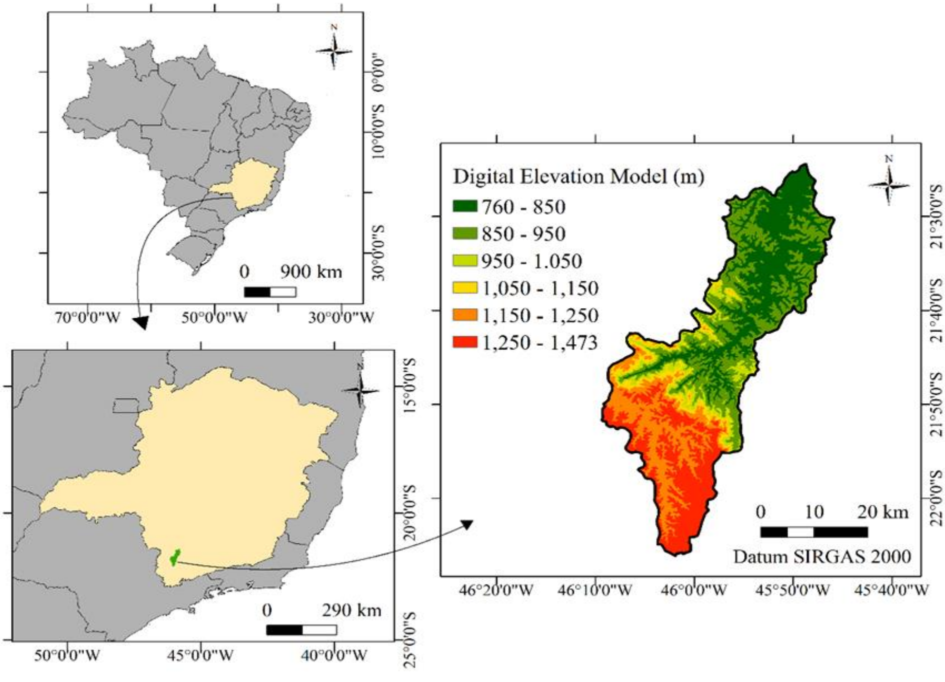

Figure 1. Study area of the Machado River Watershed, Minas Gerais, Brazil.

Climate. The Intergovernmental Panel on Climate Change (IPCC) special report on climate change and land underlines that the increase of the global mean surface temperature, relative to pre-industrial levels, may substantially affect processes involved in desertification (water scarcity), land degradation (soil erosion, vegetation loss, wildfire, permafrost thaw) and food security (Panagos *et al.*, 2021). Climate change and land use change are recognized as the main drivers of future soil erosion dynamics (Poesen, 2018).

The climate in the studied area is Tropical (Cwa), with a dry season between April and September, and a rainy season, between October and March, according to the Köppen-Geiger classification (Reboita *et al.*, 2015). The average annual precipitation and the average annual compensated temperature considering a historical series of 30 years, from 1981 to 2010, are 1,597 mm and 19.8° C, respectively (INMET, 2021).

Geology. The geological framework of the area consists of the following lithotypes: paragneisses, orthogneisses, quartzites, migmatites, biotite schist and associated granitoids (CPRM, 2014). The geological substrate has low permeability and high resistance to erosion, presenting rocky outcrops in the upper course of the Machado River and in steep areas (Servidoni *et al.*, 2019).

Soils. The pedological units, according to the Brazilian Soil Classification System (SiBCS) of EMBRAPA (2018) (Figure 2A), are the Haplic Cambisol, which predominates in the southern sector of the conservation unit, and the Red-yellow Latosol in the other sectors, with soils of the Red-yellow Argisol and Haplic Nitosol types in the northern sector (UFV *et al.*, 2010). The soil map of the area was adapted from the "Soil Map of the State of Minas Gerais" in a scale of 1:650,000 (UFV *et al.*, 2010). The relief of the area is predominantly smooth undulating, with an average slope between 3 and 8% (TOPODATA, 2008, EMBRAPA, 2013). The altitudes vary from 760 m, on the Machado River plain, to 1,470, mainly on the hills of the southern sector (Figure 1). The slope map (Figure 2B) was prepared with percentage values, from the Digital Elevation Model (DEM) covering the area, with a spatial resolution of 30 m (TOPODATA, 2008), using the ArcGis 10.5 Slope tool (ESRI, 2016).

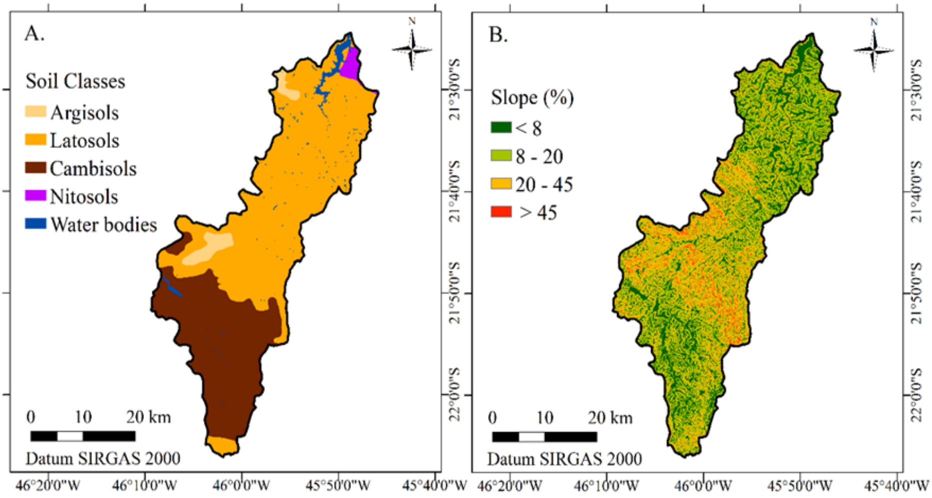

Figure 2. Soil classes (A) and slope (B) maps of the Machado River watershed, Minas Gerais, Brazil.

Land use. The study area has a predominance of the Atlantic Forest Biome, with transition to Cerrado (Savanna) to the north. In land use, temporary and permanent crops are highlighted, such as corn and coffee, respectively, in addition to forestry and pasture for cattle raising (Santos, 2019, MAPBIOMAS, 2020). The land use map considering the year 2020 (Figure 3) was obtained from the digital platform MapBiomas Project (2020), with a spatial resolution of 30 m.

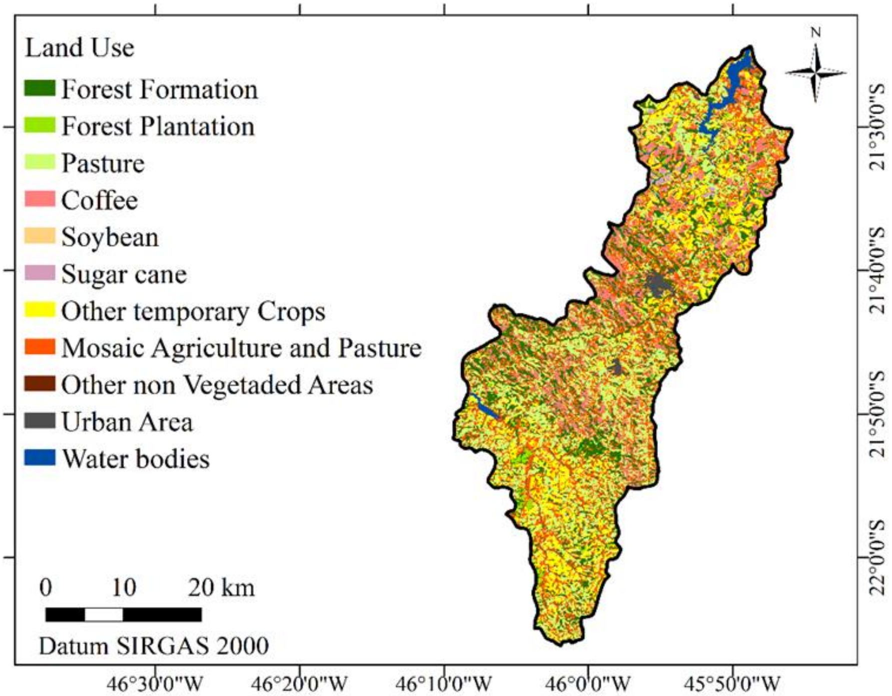

Figure 3. Land use map of the Machado River Watershed, Minas Gerais, Brazil. Adapted from the MapBiomas (2020).

The Erosion Potential Method (EPM). Soil erosion can present a major threat to agriculture due to loss of soil, nutrients, and organic carbon. Therefore, soil erosion modelling is one of the steps used to plan suitable soil protection measures and detect erosion hotspots (Bezak *et al*, 2021). For the modelling and analysis of soil erosion intensity in the Machado River Basin of the Minas Gerais, (Brazil), we used the IntErO model with the Erosion Potential Method in its algorithm background.

The EPM (Gavrilovic, 1972) considers factors dependent on climate, soil properties, topographic characteristics, land use and the degree of erosion of the watershed. Initially, the EPM estimates the susceptibility to the erosion process by calculating the erosion intensity coefficient (Z). Areas with a value of $Z > 1.00$ have high susceptibility to erosion, while areas with $Z < 0.19$ have a low tendency to the occurrence of the phenomenon (Gavrilovic, 1962). The Z parameter is calculated according to Equation 1:

$$Z = Y \cdot X_a \cdot \left(\varphi + \sqrt[2]{I_{sr}}\right) \qquad \text{Equation 1}$$

where: Y = soil resistance to water erosion, dimensionless; X_a = coefficient of land use and management, dimensionless; φ = coefficient of degree of erosive features, dimensionless and I_{sr} = mean slope of the area in %.

The Y parameter represents the soil resistance to water erosion and varies depending on the type of soil and its source material, having values between 0.20 and 2.00. The most resistant soils have values close to 0.20, while those more susceptible to erosion have values close to 2.00. The Y factor was determined for each soil class according to Sakuno *et al.* (2020), and its average value, considering the entire studied area, was 0.7.

Parameter X_a expresses the protection of the watershed against the erosive action of rain, considering the existing vegetation cover, and its values range from 0.05 (areas covered by dense vegetation) to 1.0 (areas with the presence of soil exposed). In the study area, the X_a parameter was determined for each land use class according to Sakuno *et al.* (2020), and its mean value for the entire study area was 0.54.

Factor φ represents the characteristics of erosive features observed in the field, ranging from 0.10, for areas without evidence of erosive processes, to 1.00, for areas affected by severe erosive processes, such as gullies. Through field surveys, it was verified that the occurrence of laminar erosion predominates in the watershed, thus the value of 0.5 was adopted for the parameter φ throughout of the MRW.

The I_{sr} factor (%) indicates the influence of relief on the erosive dynamics, and was obtained from the slope map, showing that the area has an average slope of 4.5%.

Using the Z coefficient, the EPM estimates the total soil loss (W_{yr}) in Mg ha^{-1} ano^{-1}, according to Equation 2:

$$W_{yr} = \left(\sqrt[2]{\frac{t_0}{10} + 0.1}\right) \cdot H_{yr} \cdot \pi \cdot \sqrt[2]{Z^3} \cdot Ds \qquad \text{Equation 2}$$

where: t_0 = average air temperature, in °C; H_{yr} = total annual precipitation, in mm; Ds = average soil density in kg dm^{-3}.

The parameters H_{yr} (mm) and t_0 (ºC) represent the influence of climatic factors on erosive dynamics and were obtained for the year 2020 based on a rainfall station located inside the watershed, at coordinates 45°53'35” W; 21°39'55” S, regulated by the National Institute of Meteorology (INMET, 2021). In the watershed, in the year 2020, the total annual precipitation was 1,534 mm and the average annual temperature was 20.5° C.

Finally, the Ds coefficient (kg dm^{-3}) demonstrates the average soil density, and its value was adopted for the study area according to Lense *et al.* (2019), being 1.21 kg dm$^{-3.}$

Obtaining the parameters as well as all the processing and modelling steps were developed with the aid of a Geographic Information System, using the ArcGis 10.5 software (ESRI, 2016).

The results estimated by using the IntErO model - EPM were compared with the soil loss tolerance limits (T). T can be defined as the maximum erosive intensity that still allows for sustainable agricultural production (Wischmeier and Smith, 1978). T values were obtained for each soil class based on the results of Lense *et al*. (2019), who calculated the T using the methodology of Bertol and Almeida (2000), which is the most recent and most used in Brazilian soils. The T values adopted were 7.40 Mg ha^{-1} yr^{-1} for Latosols, 4.75 Mg ha^{-1} yr^{-1} for Cambisols and 7.20 Mg ha^{-1} yr^{-1} for Argisols/Nitosols.

The IntErO model. The IntErO model uses the Erosion Potential Method in its algorithm background (Spalevic, 2011; Ouallali *et al*, 2020). The IntErO model is an upgrading of the River Basins (Spalevic, 1999; Spalevic *et al*., 2000) and the Surface and Distance Measuring (Spalevic, 1999) programs.

The model calculate a large number of data with the processing of 22 input parameters, returning, after the processing, 26 result parameters (Coefficient of the river basin form, *A*; Coefficient of the watershed development, *m*; Average river basin width, *B*; (A)symmetry of the river basin, *a*; Density of the river network of the basin, *G*; Coefficient of the river basin tortuousness, *K*; Average river basin altitude, *Hsr*; Average elevation difference of the river basin, *D*; Average river basin decline, *Isr*; The height of the local erosion base of the river basin, *Hleb*; Coefficient of the erosion energy of the river basin's relief, *Er*; Coefficient of the region's permeability, *S1*; Coefficient of the vegetation cover, *S2*; Analytical presentation of the water retention in inflow, *W*; Energetic potential of water flow during torrent rains, 2*gDF*½; Maximal outflow from the river basin, *Qmax*; Temperature coefficient of the region, *T*; Coefficient of the river basin erosion, Z; Production of erosion material in the river basin, *Wyear*; Coefficient of the deposit retention, *Ru*; Real soil losses, *Gsp*; Real soil losses per km^2. The model considers six factors related to lithology (rocks permeability in percent: *fp*, permeable; *fpp* semipermeable, *fo*, low permeability) and soil type (erodibility coefficient *Y*), topographic and relief data (*I* coefficient), monthly mean and annual precipitation (*P* coefficient), temperatures annual averages (*t* coefficient), land cover data (*X* coefficient) and the state of erosion patterns and development of the watercourse network (*Φ* coefficient).

The IntErO model can be characterized as semi-quantitative because it is based on a combination of descriptive and quantitative procedures. However, compared to other semi-quantitative methods, this is the most quantitative because it uses descriptive evaluation for three parameters only: soil erodibility, soil protection and extent of erosion in the catchment. All other parameters are quantitative catchment descriptors (Spalevic *et al*., 2020).

IntErO flowchart is presented in the Figure 4.

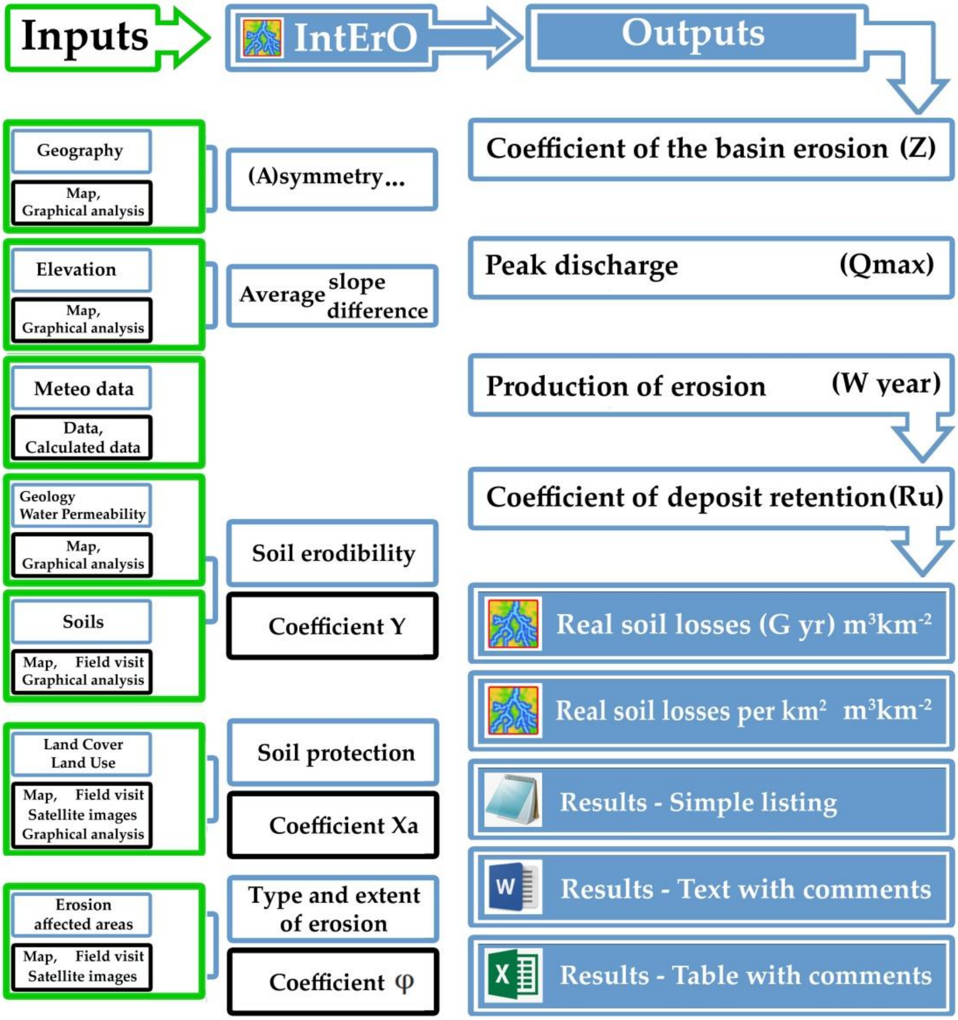

Figure 4. IntErO model Flow chart (based on Spalevic *et al.*, 2020)

RESULTS AND DISCUSSION

The Machado River Watershed showed a total soil loss of about 2 million tons per year, and an average soil loss of 18.2 Mg ha^{-1} yr^{-1} (Figure 5).

The greatest soil losses per hectare (between 25 and 50 and > 50 Mg ha^{-1} yr^{-1}) are concentrated in the southern sector of the watershed, which is partly related to the fact that this sector presents the Haplic Cambisol (CXbd), as predominant soil class.

The haplic Cambisol has the lowest resistance to water erosion among the other classes of soil in the study area, with a value of 0.9 for the Y coefficient (Table 1). In this context, Silva *et al*. (2005), in their study on soil degradation by water erosion, found an average annual loss of soil about 14 times greater for the Haplic Cambisol compared to the Red Latosol.

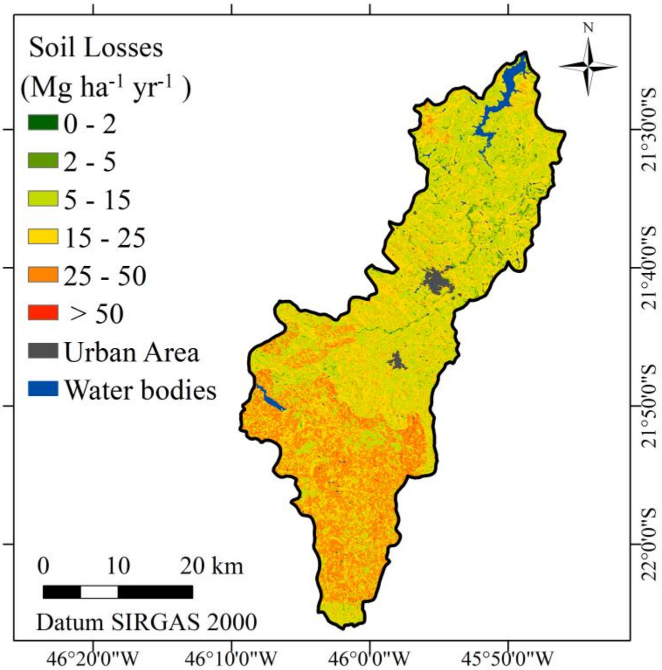

Figure 5. Map of spatial distribution of soil losses in the Machado River Watershed, Minas Gerais, Brazil.

It is noteworthy that the Haplic Cambisol is the second most abundant soil type in the watershed, occupying around 33% of its territory. Due to the low resistance to water erosion of Cambisols, it is necessary that the uses of this soil are subject to conservation measures, such as the implementation of agricultural management techniques and the mitigation of runoff and water erosion.

Table 1. Resistance to water erosion (Y) of soils in the Machado River Watershed, Minas Gerais, Brazil

Soil classes	**Area (%)**	**Y values**
Haplic Cambisol	33.48	0.9
Red-yellow Latosol	60.75	0.6
Haplic Nitosol	1.27	0.7
Red-yellow Argisol	3.00	0.8

Source: Adapted from Sakuno *et al*. (2020)

In addition, the southern sector of the area has a high Y coefficient, and the relief is soft, with a declivity of less than 8%, which favors the agro pastoral use of this area, which defines the predominant land cover and uses ("other temporary crops", with an X_a of 0.7; "pasture" with an X_a of 0.5; and "agricultural and grazing mosaic" with an X_a of 0.7) (Table 2). These uses offer low soil protection against water erosion. Furthermore, temporary crops and pastures are more susceptible to soil degradation due to the removal of the topsoil in agricultural areas (Mafra, 2020) and the soil compaction and runoff in preferential paths in pastures (Botelho and Silva, 2004).

It is noteworthy that despite the class "other non-vegetated areas" being the one with the highest average soil loss per hectare (31.4 Mg ha^{-1} yr^{-1}), its contribution to the total soil loss in the watershed it is very low (1,434.9 Mg yr^{-1}), due to its small area (0.04% of total area) (Table 2). On the other hand, the classes "other temporary crops", "pastures" and "agriculture and pasture mosaic" had the highest total soil losses in the watershed, losing together 1,723,350.9 Mg yr^{-1}, which is due to the large area occupied by them (67.2% of the MRW).

Table 2. Values of the X_a coefficient and soil losses in the land use classes of the Machado River Watershed, Minas Gerais, Brazil.

Land use classes	Area (%)	X_a	Soil loss (Mg ha^{-1} yr^{-1})	Soil loss (Mg yr^{-1})
Forest Formation	18.10	0.3	7.6	161,328.20
Forest Plantation	0.90	0.4	11.9	12,090.90
Pasture	26.90	0.5	16.7	528,541.60
Sugar cane	0.54	0.6	14.3	9,183.40
Mosaic Agriculture and Pasture	27.05	0.7	25.5	809,121.30
Urban Area*	0.78	-	-	-
Other non-Vegetated Areas	0.04	1.0	31.4	1,434.90
Water bodies*	1.50	-	-	-
Soybean	0.49	0.7	17.7	10,193.20
Other temporary Crops	13.30	0.7	24.7	385,688.03
Coffee	10.40	0.6	18.0	21,9263.40

Source: Adapted from Sakuno *et al*. (2020).
Notes: *Areas not considered in the calculation of soil loss.

On the other hand, the smallest soil losses (between 0 and 5 Mg ha^{-1} yr^{-1}) occurred mainly in the northeast and north sectors of the watershed. These areas have a gently undulating relief, with a slope ranging from 0 to 8%), covered by coffee plantations, pasture, temporary crops and forest fragments, with an X_a coefficient of 0.6; 0.5; 0.7 and 0.3, respectively (Table 2). Although clustered crops and pastures have potentially high susceptibility to water erosion, growing coffee and forest fragments are good protections for the soil against erosion, as vegetation with higher biomass control runoff more effectively (Bigarella, 2007).

In addition to the above factors, the areas that suffered the least loss of soil in the north and northeast sectors are Red-yellow Latosols, which have the highest erosion resistance among the watershed soils, with a Y of 0.6 (Table 1).

In general, the MRW is classified in category IV of erosion intensity, that is, in the watershed there is a predominance of low intensity erosion processes, with a Z coefficient of 0.34.

On the other hand, considering the values of T calculated by Lense *et al.* (2019) in about 85% of watershed, soil losses are above the limits of T. The high percentage of areas with losses above T is since the watershed has many mountainous areas with large slopes, which intensify soil losses. The results show the need to adopt soil conservation management plans to reduce water erosion. In addition, this result can help in the planning of land use and occupation policies in the watershed, respecting the agricultural suitability of each soil. It is noteworthy that the T is an index to assess soil losses in the short term, since in the long term the ideal is that water erosion rates are reduced to a minimum to promote the sustainability of agricultural systems.

MRW is part of southern Minas Gerais, an important Brazilian region for coffee production. The adoption of soil conservation practices in the region has the potential to reduce the loss of nutrients and organic matter in the soil due to water erosion and, thus, favour an increase in coffee production.

CONCLUSIONS

In 2020, the MRW presented an average soil loss of 18.2 Mg ha^{-1} yr^{-1}. The greatest soil losses per hectare occurred in non-vegetated areas and in agricultural and pasture mosaics, being 31.4 and 25.5 Mg ha^{-1} yr^{-1}, respectively. In about 85% of the MRW region, soil losses were greater than tolerable limits, which highlight the need to adopt a comprehensive soil conservation management plan to reduce soil losses from water erosion.

The results of estimating the intensity of erosion processes and potential soil losses by the IntErO – EPM method can serve as a support to the environmental planning and sustainable use of soils in the MRW, having the advantage of being an effective, simple, and low-cost method in application.

ACKNOWLEDGEMENTS

To the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for granting a scholarship to for the first and fourth authors. To the Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) for the scholarship offered to the third author.

Study was partially funded by the CAPES - Financial Code 001. The authors are grateful to the anonymous reviewers and the Editorial team for their insightful comments and suggestions.

REFERENCES

Artemyeva, Z.; Danchenko, N.; Kirillova, N.; Masyutenko, N.; Dubovik, E.; Kuznetsov, A. & Kogut, B. (2021). The Effect of Erosion Processes on the Content and Composition of Organic Matter in Macro-and Micro aggregates of Haplic Chernozem. Eurasian Soil Science. 54. 1659–1667. _

Bertol, I.& Almeida, J.A. (2000). Tolerância de perda de solo por erosão para os principais solos do Estado de Santa Catarina. Revista Brasileira de Ciência do Solo, 24(3): 657-668.

Bezak, N,; Mikoš, M.; Borrelli, P.; Alewell, C.; Alvarez, P.; Alexandre Ayach Anache, J.; Baartman, J.; Ballabio, C.; Biddoccu, M.; Cerdà, A.; Chalise, D.; Chen, S.; Chen, W.; De Girolamo, A.; Desta Gessesse, G.; Deumlich, D.; Diodato, N.; Efthimiou, N.; Erpul, G.; Fiener, P.; Freppaz, M.; Gentile, F.; Gericke, A.; Haregeweyn, N.; Hu, B.; Jeanneau, A.; Kaffas, K.; Kiani-Harchegani, M.; Lizaga Villuendas, I.; Li, C.; Lombardo, L.; López-Vicente, M.; Esteban Lucas-Borja, M.; Maerker, M.; Miao, C.; Modugno, S.; Möller, M.; Naipal, V.; Nearing, N.; Owusu, S.; Panday, D.; Patault, E.; Valeriu Patriche, C.; Poggio, L.; Portes, R.; Quijano, L.; Reza Rahdari, M.; Renima, M.; Francesco Ricci, G.; Rodrigo-Comino, J.; Saia, S.; Nazari Samani, A.; Schillaci, C.; Syrris, V.; Soo Kim, H.; Noses Spinola, D.; Tarso Oliveira, P.; Teng, H.; Thapa, R.; Vantas, K.; Vieira, D.; Yang, J.; Yin, S.; Antonio Zema, D.; Zhao, G. & Panagos, P. (2021). Soil erosion modelling: A bibliometric analysis. Environmental Research, 197, 111087.

Bigarella, J.J. (2007). Estrutura e origem das paisagens tropicais e subtropicais. 2. ed. Florianópolis, Ed. da UFSC. 1436 pp.

Botelho, R.G.M. & Silva, A.S. (2004). Bacia Hidrográfica e Qualidade Ambiental. In: Vitte, A.C. & Guerra, A.J.T., orgs. Reflexões sobre a Geografia Física no Brasil, pp. 153-188. Rio de Janeiro, RJ, Bertrand Brasil. 280 pp.

CPRM - Companhia de Pesquisa de Recursos Minerais. Mapa geológico no Estado de Minas Gerais. 2014. Available in: <http://www.portalgeologia.com.br/>. Access on: 03 Nov. 2021.

Darvishan, A.K.; Behzadfar, M.; Spalevic, V.; Kalonde, P.; Ouallali, A.; El Mouatassime, S. (2017). Calculation of sediment yield in the S2-1 watershed of the Shirindareh River Basin, Iran. Agriculture and Forestry, 63(3): 23-32.

Dragicevic, N.; Karleusa, B. & Ozanic, N. (2016). A review of the Gavrilovic method (Erosion Potential Method) application. Gradevinar, 9(68): 715-725.

Dragicevic, N.; Karleusa, B. & Ozanic, N. (2017). Erosion Potential Method (Gavrilovic method) sensitivity analysis. Soil and Water Research, 12(1): 51-59. doi:10.17221/27/2016-SWR

De Vente, J.& Poesen, J. (2005). Predicting soil erosion and sediment yield at the basin scale: Scale issue and semi-quantitative models. Earth Sciences Reviews. 71:95–125.

Efthimiou, N.; Lykoudi, E.; Panagoulia, D. & Karavitis, C. (2016). Assessment of soil susceptibility to erosion using the EPM and RUSLE models: The case of Venetikos River Catchment. Global NEST Journal., 18: 164–179.

El Mouatassime, S.; Boukdir, A.; Karaoui, I.; Skataric, G.; Nacka, M.; Darvishan, A.K.; Sestras, P. & Spalevic, V. (2019). Modelling of soil erosion processes and runoff for sustainable watershed management: Case study Oued El Abid Watershed, Morocco. Agriculture and Forestry, 65(4): 241-250.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. (2018). Sistema Brasileiro de Classificação de Solos. 9th ed. Rio de Janeiro: EMBRAPA Solos. 186 pp.

ESRI - Environmental Systems Research Institute (2016). ARCGIS Professional GIS for the desktop version 10.5. Redlands, Califórnia, Software. Retrieved from https://desktop.arcgis.com/en/arcmap/10.5/get-started/setup/arcgis-desktop-quick-start-guide.htm.

Gavrilovic S. (1972). Engineering of torrential flows and erosion. Izgradnja. Beograd p 272.

Gavrilovic, S. (1962). Method for estimating the average annual quantity of sediments according to the potency of erosion. Bulletin of the Faculty of Forestry, 26: 151-168.

Guerra, A.J.T. & Mendonça, J.K.S. Erosão dos Solos e a Questão Ambiental. In: Vitte, A.C. & Guerra, A.J.T., orgs. Reflexões sobre a Geografia Física no Brasil, p. 225-251. Rio de Janeiro, RJ, Bertrand Brasil. 280 pp.

IEF - Instituto Estadual de Florestas. Área de Proteção Ambiental - APA. Available in: <http://www.ief.mg.gov.br/component/content/article/3306-nova-categoria/117-area-de-protecao-ambiental-apa>. Access on: 15 July 2021.

Imamoglu, A. & Dengiz, O. (2017). Determination of soil erosion risk using RUSLE model and soil organic carbon loss in Alaca catchment (Central Black Sea region, Turkey). Rendiconti Lincei, 28: 11-23.

INMET - Instituto Nacional de Meteorologia. Banco de Dados Meteorológicos do INMET. Available in: <https://bdmep.inmet.gov.br/#>. Access on: 03 Aug. 2021.

INMET - Instituto Nacional de Meteorologia. Normais Climatológicas do Brasil: 1981 a 2010. Available: <https://portal.inmet.gov.br/normais>. Access on: 01 Aug. 2021.

Justino, R.C.; Mataveli, G.A.V.; Kawakubo, F.S.; Guerrero, J.V.R. & Chaves, M.E.D. (2019). Mapeamento do uso da terra e Áreas de Preservação Permanente (APP) nas bacias hidrográficas dos rios São Tomé e Machado, sul de Minas Gerais. Revista de Geografia, 9(1): 51-65.

Kavian, A.; Gholami, L.; Mohammadi, M.; Spalevic, V.; & Falah Soraki, M. (2018). Impact of Wheat Residue on Soil Erosion Processes. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 46(2), 553-562.

Kavian, A.; Hoseinpoor Sabet, S.; Solaimani, K. & Jafari, B. (2017). Simulating the effects of land use changes on soil erosion using RUSLE model. Geocarto International 3(1):97-111.

Khaledi Darvishan, A.; Homayounfar, V.; Sadeghi, SHR. (2016). The impact of standard preparation practice on the runoff and soil erosion rates under laboratory conditions. Solid Earth 7(5): 1293-1302.

Latuf, M.O.; Chinen, H.S.S.; Musselli, D.G. & Carvalho, P.H.S. (2019). Outorgas de uso dos recursos hídricos na Área de Proteção Ambiental do Rio Machado, sul de Minas Gerais. Caminhos de Geografia, 20(71): 311-327.

Lense, G.H.E.; Avanzi, J.C.; Parreiras, T.C. & Mincato, R.L. (2020). Effects of deforestation on water erosion rates in the Amazon region. Revista Brasileira de Ciências Agrárias, 15(4): e8500.

Lense, G.H.E.; Moreira, R.S.; Parreiras, T.C.; Silva, L.F.P.M.; Teodoro, A.E.M.; Santana, D.B.; Bolelli, T.M. & Mincato, R.L (2019). Assessment of Soil Loss Tolerance limit to Latosol, Argisol and Cambisol in the Southern Minas Gerais State. Caderno de Ciências Agrárias, 11:1–6.

Lense, G.H.E.; Parreiras, T.C.; Moreira, R.S.; Avanzi, J.C. & Mincato, R.L. (2019). Estimates of soil losses by the erosion potential method in tropical latosols. Ciência e Agrotecnologia, 43: e012719.

Lovric, N. & Tosic, R. (2018). Assessment of soil erosion and sediment yield using erosion potential method: Case study - Vrbas river basin (B&H). Bulletin of the Serbian Geographical Society, 98: 1-14.

Mafra, N.M.C. (2020). Erosão e planificação de uso do solo. In: Guerra, A.J.T.; Silva, A.S. & Botelho, R.G.M., orgs. Erosão e conservação dos solos, pp. 301-322. Rio de Janeiro, RJ, Bertrand Brasil. 339 pp.

MAPBIOMAS (2020). Coleção 6 da Série Anual de Mapas de Uso e Cobertura da Terra do Brasil, 2020. Available in: <https://mapbiomas.org/download>. Access on: 04 Oct. 2021.

Mohamadi, MA.& Kavian, A. (2015). Effects of rainfall patterns on runoff and soil erosion in field plots. International Soil and Water Conservation Research 3: 273-281.

Nearing, M.A.; Jetten, V.; Baffaut, C.; Cerdan, O.; Couturier.; A.; Hernandez, M.; Le Bissonnais, Y.; Nichols, M.H.; Nunes, J.P.; Renschler, C.S.; Souchere, V. & Van Oost, K. (2005). Modelling response of soil erosion and runoff to changes in precipitation and cover. Catena 61:131-154.

Nikolic, G.; Spalevic, V.; Curovic, M.; Darvishan, A.K.; Skataric, G.; Pajic, M.; Kavian, A. & Tanaskovik, V. (2018). Variability of Soil Erosion Intensity Due to Vegetation Cover Changes: Case Study of Orahovacka Rijeka, Montenegro. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 47(1): 237-248.

Ouallali, A.; Aassoumi, H.; Moukhchane, M.; Moumou, A.; Houssni, M.; Spalevic, V.; & Keesstra, S. (2020). Sediment mobilization study on Cretaceous, Tertiary and Quaternary lithological formations of an external Rif catchment, Morocco. Hydrological Sciences Journal, 65, 9: 1568-1582.

Panachuki, E.; Alves Sobrinho, T.; Vitorino, A.C.T.; Carvalho, D.F. & Urchei, M.A. (2006). Parâmetros físicos do solo e erosão hídrica sob chuva simulada, em área de integração agricultura-pecuária. Revista Brasileira de Engenharia Agrícola e Ambiental, 10(2): 261-268.

Panagos, P.; Ballabio, C.; Himics, M.; Scarpa, S.; Matthews, F.; Bogonos, M.; Poesen, J.; Borrelli, P. (2021). Projections of soil loss by water erosion in Europe by 2050. Environmental Science & Policy, 124, 380-392.

Panagos, P.; Borrelli, P.; Poesen, J.; Ballabio, C.; Lugato, E.; Meusburger, K.; Montanarella, L. & Alewell, C. (2015). The new assessment of soil loss by water erosion in Europe. Environmental Science & Policy, 54: 438-447.

Poesen, J. (2018). Soil erosion in the Anthropocene: research needs. Earth Surf. Process. Landf. 43, 64–84.

Reboita, M.S.; Rodrigues, M.; Silva, L.F. & Alves, M.A. (2015). Aspectos climáticos do estado de Minas Gerais. Revista Brasileira de Climatologia, 17(11): 206-226.

Sakuno, N.R.R.; Guiçardi, A.C.F.; Spalevic, V.; Avanzi, J.C.; Silva, M.L.N. & Mincato, R.L. (2020). Adaptation and application of the erosion potential method for tropical soils. Revista Ciência Agronômica, 51(1): e20186545.

Santana, D.B.; Bolleli, T.M.; Lense, G.H.E.; Silva, L.F.P.M.; Sestras, P.; Spalevic, V. & Mincato, R.L. (2021). Estimate of water erosion in coffee growing areas in Serra da Mantiqueira, Minas Gerais State, Brazil. Agriculture and Forestry, 67 (2): 75-88.

Santos, C.A. (2019). Diagnóstico e zoneamento geoambiental da APA da bacia hidrográfica do rio Machado-MG. Caderno de Geografia, 29(1): 144-163.

Santos, G.C.; Griebeler, N.P. & Oliveira, L.F.C. (2010). Chuvas intensas relacionadas à erosão hídrica. Revista Brasileira de Engenharia Agrícola e Ambiental, 14(2): 115-123.

Servidoni, L.E.; Teodoro, A.E.M.; Mincato, R L. & Santos, C.A. (2019). Avaliação de risco a enchentes e inundações por krigagem ordinária em sistemas de informação geográfica. Caderno de Geografia, 29(1): 126-143.

Silva, A.M.; Silva, M.L.N.; Curi, N.; Lima, J. M.; Avanzi, J.C. & Ferreira, M.M. (2005). Perdas de solo, água, nutrientes e carbono orgânico em Cambissolo e Latossolo sob chuva natural. Pesquisa Agropecuária Brasileira, 40(12): 1223-1230.

Silva, R.M.; Celso, A.G.S. & Silva, A.M. (2014). Predicting soil erosion and sediment yield in the Tapacurá Catchment, Brazil. Journal of Urban and Environmental Engineering, 8(1): 75-82.

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, Faculty of Agriculture of the University of Belgrade, Serbia, 1999: 135p.

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

Spalevic, V.; Barovic, G.; Vujacic, D.; Curovic, M.; Behzadfar, M.; Djurovic, N.; Dudic, B.; Billi, P. (2020). The Impact of Land Use Changes on Soil Erosion in the River Basin of Miocki Potok, Montenegro. Water 2020, 12, 2973-3000.

Spalevic, V.; Djurovic, N.; Mijovic, S.; Vukelic-Sutoska, M. &Curovic, M. (2013). Soil erosion intensity and runoff on the Djuricka River Basin (North of Montenegro). Malaysian Journal of Soil Science, 17(1):49-68.

Spalevic, V.; Dlabac, A.; Spalevic, B.; Fustic, B. & Popovic, V. (2000). Application of computer - graphic methods in the research of runoff and intensity of ground erosion - I program "River basins". Agriculture and Forestry 2000, 46, 1-2: 19-36.

Spalevic, V.; Lakicevic, M.; Radanovic, D.; Billi, P.; Barovic, G.; Vujacic, D.; Sestras, P. & Khaledi Darvishan, A. (2017). Ecological-Economic (Eco-Eco) modelling in the river basins of Mountainous regions: Impact of land cover changes on sediment yield in the Velicka Rijeka in Montenegro. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 45(2): 602-610.

Spalevic, V.; Radanovic, D.; Skataric, G.; Billi, P.; Barovic, G.; Curovic, M.; Sestras, P. & Darvishan, A.K. (2017). Ecological-Economic (Eco-Eco) modelling in the mountainous river basins: Impact of land cover changes on soil erosion. Agriculture and Forestry, 63(4): 9-25.

Stefanidis, S. & Stathis, D. (2018). Effect of Climate Change on Soil Erosion in a Mountainous Mediterranean Catchment (Central Pindus, Greece). Water, 10(10): 1-12.

Tavares, A.S.; Uagoda, R.E.S.; Spalevic, V. & Mincato, R.L. (2021). Analysis of the erosion potential and sediment yield using the IntErO model in an experimental watershed dominated by karst in Brazil. Agriculture and Forestry, 67 (2): 153-162.

TOPODATA: banco de dados geomorfométricos do Brasil. (2008). Acesso. Available in: <http://www.dsr.inpe.br/topodata/>. Access on: 25 Aug. 2021.

Tazioli, A. (2009). Evaluation of erosion in equipped basins: preliminary results of a comparison between the Gavrilovic model and direct measurements of sediment transport. *Environmental Geology,* 56(5): 825-831.

UFV; CETEC; UFLA & FEAM (2010). Mapa de Solos do Estado de Minas Gerais. Belo Horizonte, Fundação Estadual do Meio Ambiente. 49 pp. Available in: <http://www.feam.br/noticias/1/949-mapas-de-solo-do-estado-de-minas-gerais>. Access on: 10 Oct. 2021.

Wischmeier, W.H. & Smith, D.D. (1978). Predicting rainfall erosion losses. A guide to conservation planning. Supersedes Agriculture Handbook. Washington, United States Department of Agriculture. 67p.