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Original Research

Application of USLE, GIS, and Remote Sensing in the Assessment of Soil Erosion Rates in Southeastern Serbia

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Abstract

The assessment of soil erosion rate and its spatial distribution in the hilly-mountainous Nisava River basin was conducted by Universal Soil Loss Equation (USLE) model through a GIS-based approach. A Landsat 7 Enhanced Thematic Mapper (ETM+) image and normalized difference vegetation index (NDVI) were used for the determination of crop management factor.

The average annual soil loss was estimated at 13.1 t·ha^{-1}·yr^{-1}, classifying the Nisava River basin under the high erosion rate category. About 44.1% of the watershed area was characterized by slight erosion rate (< 5 t·ha^{-1}·yr^{-1}), 15.5% of the area was found to be under moderate erosion rate (5-10 t·ha^{-1}), 18.9% of the area was under high erosion rate (10-20 t·ha^{-1}), while around 14.4% of the area was under a very high erosion rate (20-40 t·ha^{-1}·yr^{-1}). Severe erosion rates (40-80 t·ha^{-1}·yr^{-1}) were observed at 5.9% of the study area (168 km^2), whereas very severe erosion rate (>80 t·ha^{-1}·yr^{-1}) described about 1.3% of the watershed (35.9 km^2). The highest erosion was found on a sloppy terrain with agricultural activity. The results of this work are in agreement with previous studies conducted in the watershed, which indicates the presented methodology could be applied with eventual further improvements for the evaluation of erosion factors on soil resources in Serbia when limited data are available.

Keywords: USLE, GIS, NDVI, Serbia, Nisava River basin

Introduction

Soil erosion is a complex process determined by climatic regime, surface cover, and landscape characteristics, and it can be modified by human activities. Human-induced erosion is typical to the regions with intensive agricultural production, and other human activities such as mining and construction, and intensive deforestation. Planning of soil conservation measures requires knowledge of the factors that cause loss of soil. Despite its disadvantages, the empirical equation of USLE [1] remains the most popular tool for water erosion hazard assessment due to modest data demand and transparent model structure. Although the original model was developed for agricultural areas with slopes from 3% to 18%, its successful use with or without modification in hilly and mountain regions was reported [2-4]. Regional assessment of soil erosion with USLE was con-

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ducted in the past on numerous watersheds of different sizes [5-8]. USLE is used jointly with a GIS, which facilitates the application, data editing, and elaboration, and gives the possibility to present the results using thematic maps of different format and scale. An added value to this is the use of remote sensing data in mapping soil erosion assessment [2, 9].

This study aims to assess the applicability of a methodology, based on the application of the USLE model, GIS technology, and remote sensing images, for the determination of soil erosion rate in the Nisava River watershed in southeastern Serbia.

Study Area

The Nisava River basin is located in southeastern Serbia between 21º45’44” and 23º0’49” east longitude and 42º51’55” and 43º24’20” north latitude. Nisava is a transboundary river that enters Serbia from Bulgaria. Total surface area of the river basin in Serbia is about 2,848 km^2. Nisava is the longest river in southeastern Serbia at 218 km. The area is characterized with hilly-mountainous terrain in most of the basin and alluvial plane downstream and around water course. An average elevation of the basin is 757.8 m, with average slope of 22.6%. The elevation ranges from 2169 m a.s.l. at Old Mountain (Midzor) to 174 m a.s.l. in the western part of the basin at the mouth of the Nisava to the South Morava River, indicating high altitudinal gradients among the basin area. The Nisava flows from southeast to northwest, and the basin area is much wider in its upper part than in the lower part (Fig. 1). The Nisava is characterized by high water level fluctuations and with a very developed hydrographic network. Climate in study area is temperate continental, typical for Balkan Peninsula. Average annual rainfall is 604.6 mm. Soil cover is heterogeneous and consists of 11 reference soil groups that have been formed on calcareous, igneous, and metamorphic rocks. Forests occupy 33% of the Nisava basin. Agricultural production faced de-intensification in the last two decades due to severe migration to urban areas. It also is characterized by small farming systems. Pastures and meadows cover 15-44% of the catchment area, arable land 15-36%, and only 2-6% of the catchment is under grapevine cultivation. The study area faces many environmental problems such as land and soil degradation, soil erosion, mud- and landslides, and forests fires.

Methodology

In the USLE model soil erosion is estimated as the product of empirical coefficients, which must therefore be accurately evaluated. Four main factors are generally considered: soil, topography, land use, and climate [1]. The magnitude of these factors varies considerably in space and time, but the model averages out the results in the long run. A well known form of USLE equation is:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad (1)$$

...where: A – average annual soil loss rate (t·ha^{-1}·yr^{-1}), R – rainfall erosivity factor (MJ mm·ha^{-1}·h^{-1}·yr^{-1}), K – soil erodibility factor (t·ha·h·ha^{-1}·MJ^{-1}·mm^{-1}), LS – topographic factor (dimensionless), C – crop management factor (dimensionless), and P – conservation supporting practice factor (dimensionless), set to one in this study, assuming no conservation measures have been implemented in the study area.

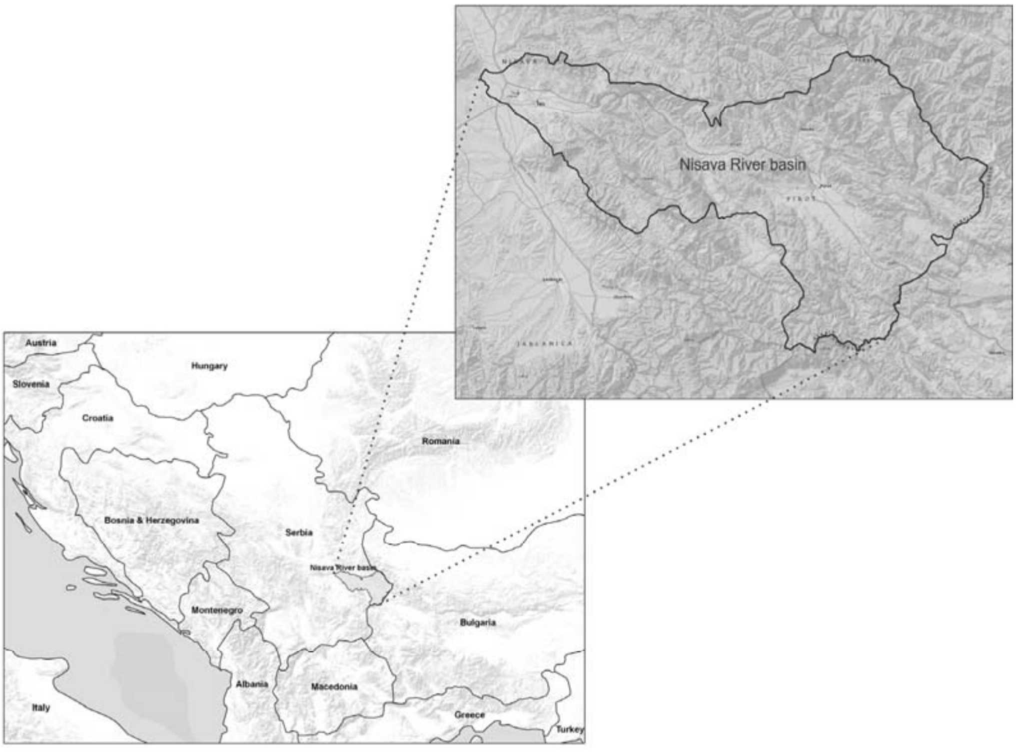

Fig. 1. Location of the Nisava River basin on the Balkan peninsula.

USLE model input data belong to historical weather datasets, soil maps, digital elevation models (DEM), and land cover derived from Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images. ArcGIS was used as a tool to manage data and perform the computations using the raster data format.

A simple structure of USLE makes it easy to define the policy scenarios by changing C and P factors of Eq. 1 under given natural conditions described by *R*, *K*, *L*, and *S* factors. Therefore, it may be a useful soil conservation measures tool.

Each factor of Eq. 1 is described in the GIS as a specific thematic layer and an overlay of these layers, through appropriate map algebra functions, it permits the presentation of modeling results as a spatially distributed soil loss in a basin [10].

Rainfall erosivity factor represents the erosivity of rainfall at a particular location. As there were no records of rainfall intensity in the Nisava basin available, the records of monthly rainfall data were used for the determination of *R*-factor average annual value. The following relationship, developed by [1] was applied:

$$R=\sum_{i=1}^{12}1.735\cdot 10^{(1.5\cdot\log_{10}\cdot(P_i^2/P)-0.08188)} \qquad (2)$$

...where: R – rainfall erosivity factor in $\mathrm{MJ\cdot mm\cdot ha^{-1}\cdot yr^{-1}}$, P_i – monthly rainfall in mm, and P – annual rainfall in mm.

The rainfall erosivity map was prepared from 18 rain gauge stations, six of them located inside the watershed area, and others in its vicinity. Historical precipitation data for a period of 60 years (1949-2008) were used for obtaining average *R* values. The rainfall erosivity map (Fig. 2a) was obtained by applying the inverse distance weighting (IDW) deterministic interpolation technique [11].

Soil erodibility factor K represents the average long-term soil response to the erosive power associated with rainfall and runoff. It is an empirical measure and represents a function of intrinsic soil properties. In this study, *K* value was computed by equation [1]:

$$\begin{aligned}K&=(2.1\cdot 10^{-7}\cdot M^{1.14}\cdot(12-OM)+\\&+4.3\cdot 10^{-3}\cdot(s-2)+3.3\cdot(p-3))\cdot 0.1317\end{aligned} \qquad (3)$$

...where: K – soil erodibility factor in $\mathrm{t\cdot ha\cdot h\cdot ha^{-1}\cdot MJ^{-1}\cdot mm^{-1}}$, M – particle size parameter (% silt + % very fine sand)×(100 – % clay), OM – organic matter (%), s – soil structure code, p – soil permeability class, 0.1317 – for conversion to SI units.

A soil survey with a total of 419 soil profiles was used for the creation of the soil map, and the existing data on soil profiles were used for the determination of soil erodibility. The spatial distribution of soil erodibility is given in Fig. 2b.

Topographic factor (*LS*) includes two components: slope length factor (*L*) and slope steepness factor (*S*).

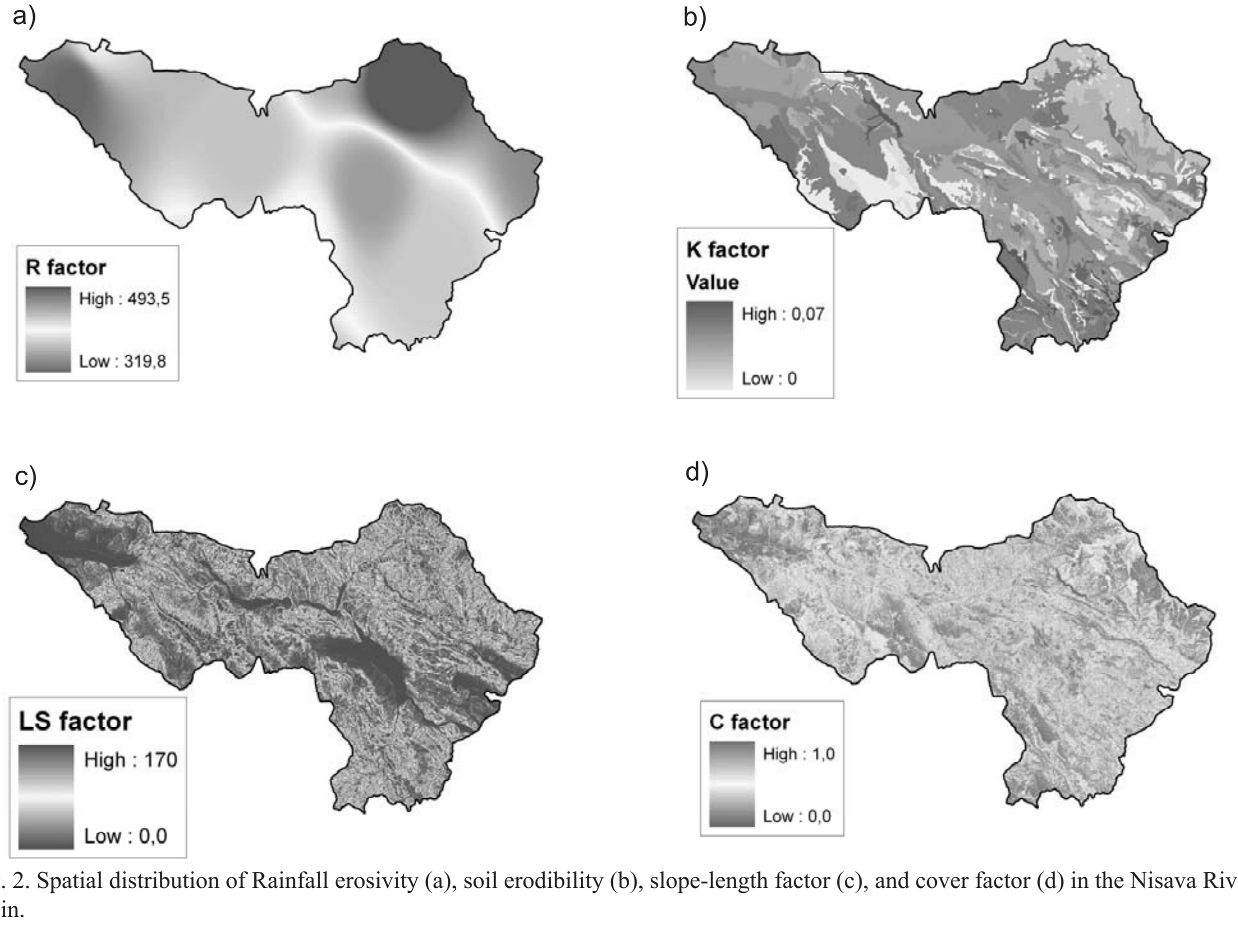

Fig. 2. Spatial distribution of Rainfall erosivity (a), soil erodibility (b), slope-length factor (c), and cover factor (d) in the Nisava River basin.

Generating the the *LS* values poses the largest problem in using USLE for soil erosion estimates [12, 13]. The basic input for generating the *LS* factor grid in GIS was 30 m DEM dataset. A DEM of the area was generated by spatial interpolation of contour lines from the survey of Serbia's toposheets 1:50,000 scale. The *L*-factor calculation was based on the relationship developed by [14]. The equation follows as:

$$L = \left(\frac{\lambda}{22.13}\right)^m \qquad (4)$$

...where λ is the horizontal projected slope length and m is the slope length exponent.

The *S*-factor was calculated based on the relationship given by [13]:

$$S = 10.8 \sin\theta + 0.03 \text{ for slopes} < 9\% \qquad (5)$$

$$S = 16.8 \sin\theta + 0.50 \text{ for slopes} > 9\% \qquad (6)$$

...where: θ – slope angle (0).

LS factor was calculated automatically by a program originally written in Arc Macro Language (AML) [15] that was updated in 2004 with the C++ programming language to be more efficient in processing [16]. Spatial distribution of LS factor in the Nisava basin is presented in Fig. 2c.

C factor was obtained through detection of vegetation cover. Landsat 7 ETM and normalized difference vegetation index (NDVI) were used. Two scenes of Landsat ETM images acquired on 22 August 2000 with a spatial resolution of 30 m were used. NDVI represents an effective indicator of the distribution of vegetation in an area and it is one of the commonly used methods for determining the *C* factor [17, 18]. NDVI measures the amount of green vegetation by determining spectral reflectance difference between Near Infrared (NIR) and red band of electromagnetic spectrum. The equation of [19] was applied in this study as:

$$NDVI = (NIR - RED)/(NIR + RED) \qquad (7)$$

NDVI-values were scaled to approximate *C*-values using the following provisional equation, developed by the European Soil Bureau [17]:

$$C = \exp\left[-\alpha \cdot \frac{NDVI}{(\beta - NDVI)}\right] \qquad (8)$$

...where: α and β are parameters that determine the shape of the NDVI-C curve. Spatial distribution of *C*-factor in the Nisava basin is presented in Fig. 2d.

Results

Each of the factors of USLE equation was derived separately in GIS, representing a specific thematic layer over the whole watershed as illustrated in Fig. 2. The average rainfall erosivity factor (*R*) for the 60-year period ranged from 319.9 MJ·mm·ha^{-1}·h^{-1}·yr^{-1} in the area of Nis (the lowest altitude in the basin) to 493.5 MJ·mm·ha^{-1}·h^{-1}·yr^{-1} on Old Mountain. Soil erodibility factor ranged from zero in the area with rock outcrops to 0.0771 in some Regosols. Cultivated soils used in agricultural production have higher erodibility values. They are represented by reference groups of Regosols, Cambisols, Vertisols, and Fluvisols. LS factor ranges from 0 to 170, while *C* factor values are between 0 and 1. Values close to 0 are a typical characteristic of forests, while higher *C* values are characteristic of cultivated land.

These thematic layers were created in a grid of 30×30 m cell size and then multiplied. The obtained results present the annual soil loss on a pixel by pixel basis (Fig. 3). The results indicate that 44.1% of the watershed area is under a slight erosion rate (< 5 t·ha^{-1}·yr^{-1}), while 15.5% of the area was found to be under a moderate erosion rate (5-10 t·ha^{-1}). A high erosion rate (10-20 t·ha^{-1}) was found on 18.9% of the study area, while around 14.4% of the area was under a very high erosion rate (20-40 t·ha^{-1}·yr^{-1}). A severe erosion rate (40-80 t·ha^{-1}·yr^{-1}) was observed in 5.9% of the study

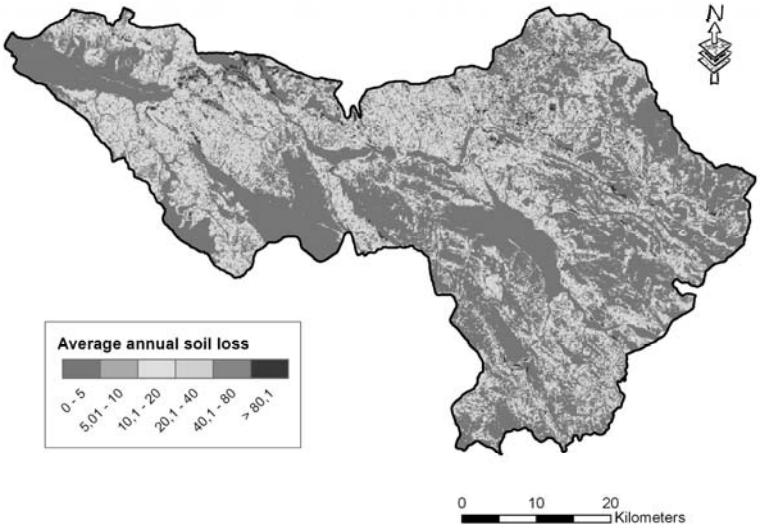

Fig. 3. Spatial distribution of average annual soil loss (t·ha^{-1}·year^{-1}) in the Nisava River basin.

Table 1. Soil erosion distribution and its characteristics on different elevation zones.

Elevation	Zone	Area	% of area	Avg. slope	Avg. erosion	Portion of erosion	Portion of erosion	Cultiv. area
		(km^2)	(%)	(%)	(t·ha^{-1})	(t·ha^{-1})	(%)	(%)
<300	1	170.9	6.0	6.5	7.01	0.42	3.2	71.8
300-400	2	591.1	20.8	14.3	14.33	2.97	22.7	67.7
400-500	3	320.8	11.3	21.4	17.93	2.02	15.4	39.3
500-600	4	316.9	11.1	23.0	15.94	1.77	13.5	28.0
600-700	5	350.2	12.3	21.8	12.44	1.53	11.7	25.3
700-800	6	267.2	9.4	24.6	13.06	1.23	9.4	17.3
800-900	7	203.6	7.1	26.9	12.38	0.89	6.8	15.1
900-1000	8	157.4	5.5	28.6	11.13	0.61	4.7	11.3
1000-1200	9	115.3	4.0	32.1	11.61	0.47	3.6	5.6
1200-1500	10	235.8	8.3	29.5	8.71	0.72	5.5	2.0
1500-1800	11	98.9	3.5	29.0	10.70	0.37	2.8	0.0
>1800	12	19.9	0.7	26.3	12.40	0.09	0.7	0.0

area (168 km^2), whereas a very severe erosion rate (>80 t·ha^{-1}·yr^{-1}) described about 1.3% of the watershed (35.9 km^2). Average soil erosion rate in the whole basin was estimated to be 13.1 t·ha^{-1}·yr^{-1}, classifying the whole basin in the high erosion rate category.

Discussion

The results obtained in this work prove the validity of the presented approach when compared with the regional soil erosion map [20], the sediment yield measurements [21] in the basin, and with other more detailed studies in the watershed [22].

The advantages of the GIS-based approach are observed in data elaboration and presentation, and in the creation of erosion risk maps. In order to obtain more information on spatial distribution of soil erosion in the Nisava basin, an analysis of erosion processes on different elevation zones was conducted (Table 1). The obtained results indicate that average erosion rates higher than basin average are in 3 elevation zones between 300 and 600 meters, while in another 9 zones average erosion rates are lower than the basin average (13.1 t·ha^{-1}). The lowest erosion is found in elevation zone 1, which has an average slope gradient of only 6.5%, and in elevation zone 10, between 1,200 and 1,500 m (8.7 t·ha^{-1}). Three zones with the highest erosion rate occupy 43.1% of the watershed, and 51.7% of total erosion expressed in t·ha^{-1} (6.77 t·ha^{-1} of total 13.1 t·ha^{-1}). The highest erosion was found between 400 and 500 m in elevation zone 3 (17.9 t·ha^{-1}) with average slope of 21.4% and 39.2% of an area subjected to arable agricultural actions. The lower values of average erosion rate in elevation zones with very high slope gradients (>25%) are related mainly to land use. Also, it is interesting to note ratios between percentage of total area of certain zones and portions of erosion (in percentage) of certain zones related to total erosion. A ratio of these two values indicates an erosion pressure in certain elevation zone as a dimensionless value. Values lower than 1 indicate higher pressure, while values higher than 1 indicate lower pressure. Erosion pressure is the highest in elevation zones 3 (0.73), 4 (0.81), and 2 (0.91) between 300 and 600 m. Therefore, it is essential to take conservation practices to reduce soil loss in the elevation zones between 300 and 600 m, which are subject to extensive agriculture practices. These zones are characterized by rainfed farming, including fruit and wine growing, and corn and potato production, which are situated on hill-slopes higher than 7%. The size of these farms is usually very small and it disables, in most cases, contour tillage as a conservation practice. Farmers usually defend soil tillage methods by operational costs and it is not expected that they will change their behavior in the future. Moreover, it is also foreseen that the soil erosion rate could decrease in the future due to the migration of the rural population to urban areas.

In this work high attention was given to the determination of *LS* factor due to the fact that our watershed is characterized with high altitudinal gradient and slopes that are much higher than those used for the USLE model creation. Hence, *LS*-factor calculation was based on the relationship developed by [14], which diminishes the obtained results on complex landscapes comparing to other *LS*-factor determination methods often used in erosion studies [23]. Taking into consideration the resolution of calculation cell used in this work, there is an assumption among authors that erosion rates could decrease if cell resolution is decreased. This was confirmed also by [24], who stated that DEM resolution decrease resulted in erosion rate decrease. Moreover, the erodibility factor in this work was determined from the results of soil survey and existing soil maps. *K* values assigned to polygons were then converted to raster format on the same cell resolution as for the other factors. This implies that the obtained results also depend on the quality of soil maps (and it is difficult to map soil in large a watershed characterized with heterogeneity of all soil forming factors). For all these reasons it is important to say that an on-field survey is necessary to test high and extreme values of erosion rates.

Conclusions

The applicability of the USLE model under Serbian conditions was demonstrated by integrating the existing information with remote sensing data and GIS technology. This study confirms the results of the previous investigations and indicates the feasibility to apply the presented approach to estimate spatial distribution of soil erosion potential in a larger scale in southeastern Serbian watersheds, in the conditions of limited data availability. In addition, the results obtained in this study could be an important reference for managing and planning land use conservation in the Nisava basin and for further identification of vulnerable areas. The results obtained in this work will be used in the future for quantitative (not only qualitative) comparison with the results obtained with the EPM model [25] in order to find a link between coefficient of erosion and erosion rates obtained with USLE.

The average annual soil loss of the Nisava basin was estimated at about 13.1 t·ha^{-1}, classifying it in the high soil erosion category. About 21.4% of the River basin was found to be under very high, severe, and extremely severe erosion rates (612.9 km^2 or 61,290 ha), while about 59.6% of the basin is slightly to moderately prone to erosion risk.

The Nisava basin is quite large and it is characterized by high spatial heterogeneity of erosion factors. In these cases, the application of USLE jointly with GIS and remote sensing is of substantial importance because it permits the faster evaluation of the actual situation and also the comparison of different mitigation measures and management scenarios under future land use and expected climate change.

Furthermore, it is also important to mention that soil surveys might be more detailed and intensive by means of determination of erosive factors and on field observation of erosion hot spots. This broader sense approach in soil survey (including soil conservation and erosion) will increase the quality of obtained results with smaller further improvements and adjustments of the methodology. In our case the use of this methodology on a national scale without modification and use of high quality input parameters for all erosive factors will be more significant for preliminary purposes than for direct conservation measurements. However, the methodology could be very useful for the direct decisions on conservation measures, especially if high quality input parameters are available.

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References

1. WISCHMEIER W.H., SMITH D.D. Predicting rainfall erosion loss: A guide to conservation planning. Agricultural Handbook No. 537. US Department of Agriculture. – Agricultural Research Service, Washington, DC, **1978**.
2. KOULI M., SOUPIOS P. Soil erosion prediction using the revised Universal Soil Loss Equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. Environ Geol **57**, 483, **2009**.
3. IRVEM A., TOPALOGLU F., UYGUR V. Estimating spatial distribution of soil loss over Seyhan River Basin in Turkey. J. Hydrol. **336**, 30, **2007**.
4. LASTORIA B., MISEROCCHI F., LANCIANI A., MONACELLI G. An Estimated Erosion Map for Aterno-Pescara River Basin. European Water **21-22**, 29, **2010**.
5. ŞTEFĂNESCU L., CONSTANTIN V., SURD V., OZUNU A., VLAD Ş-N. Assessment of soil erosion potential by the USLE method in Roşia montană mining area and associated natech events. Carpath. J. Earth Env., **6**, (1), 35, **2011**.
6. BATHRELLOS G.D., SKILODIMOU H.D., CHOUSIANITIS K.G. Soil Erosion Assessment in Southern Evia Island Using USLE and GIS. Bulletin of the Geological Society of Greece. Proceedings of the 12th International Congress, Patras, May, **XLIII**, (3), 1572, **2010**.
7. ONORI F., DE BONIS P., GRAUSO S. Soil erosion prediction at the basin scale using the revised universal soil loss equation (RUSLE) in a catchment of Sicily (southern Italy). Environ. Geol. **50**, 1129, **2006**.
8. ARGHIUS C., ARGHIUS V. The quantitative estimation of the soil erosion using USLE type ROMSEM model. Case-study - the Codrului Ridge and Piedmont (Romania). Carpath. J. Earth Env., **6**, (2), 59, **2011**.
9. KARABURUN A. Estimation of C factor for soil erosion modeling using NDVI in Buyukcekmece watershed. Ozean Journal of Applied Sciences **3**, (1), **2010**.
10. FISTIKOGLU O., HARMANCIOGLU N.B. Integration of GIS with USLE in Assessment of Soil Erosion. Water Resour. Manage. **16**, 447, **2002**.
11. SHEPARD D. A two-dimensional interpolation function for irregularly-spaced data, Proc. 23rd National Conference ACM, ACM, pp. 517-524, **1968**.
12. RENARD K.G., FOSTER G.R., WEESIES G.A., RUSLE: revised universal soil loss equation. J Soil Water Conserv **46**, (1), 30, **1991**.
13. MOORE I.D., WILSON J.P. Length-slope factors for the revised universal soil loss equation: simplified method of estimation. J Soil Water Conserv **47**, (5), 423, **1992**.
14. MCCOOL D.K., BROWN L.C., FOSTER G.R. Revised slope steepness factor for the universal soil loss equation. Trans ASAE **30**, 1387, **1987**.

15. HICKEY R., SMITH A., JANKOWSKI P. Slope length calculations from a DEM within Arc/Info GRID. Comput Environ Urban **18**, (5), 365, **1994**.
16. VAN REMORTEL R., MAICHLE R., HICKEY R. Computing the RUSLE LS Factor based on Array-based Slope Length Processing of Digital Elevation Data Using a C++ Executable. Comput. Geosci. **30**, (9-10), 1043, **2004**.
17. DE JONG S.M., RIEZEBOS H.T. SEMMED: a distributed approach to soil erosion modelling. In: Spiteri, A. (Ed.), Remote Sensing '96: Integrated Applications for Risk Assessment and Disaster Prevention for the Mediterranean. Balkema, Rotterdam, pp. 199-204, **1997**.
18. VAN DER KNIJFF J., JONES R.J.A., MONTANARELLA L. Soil erosion risk assessment in Italy. European Soil Bureau, Joint Research Center of European Commission. EUR 19022EN, **2000**.
19. JENSEN J.R. Remote Sensing of the Environment: An Earth Resource Perspective. Prentice Hall, New Jersey, **2000**.
20. LAZAREVIC R. Erosion Map of SR Serbia 1:500,000. Belgrade: Institute for forestry and wooden industry, **1983** [In Serbian].
21. MUSTAFIĆ S., KOSTADINOV S., MANOJLOVIĆ P. Risk of artificial lake “Zavoj” to processes of erosion – methodological, knowing and protecting aspect. Bulletin of the Serbian Geographical Society, Tome **LXXXVIII**, **2008** [In Serbian].
22. KOSTADINOV S. Erosion in River Visočica watershed. Erozija, **30**, 69-76, **2003** [In Serbian].
23. MITASOVA H., HOFIERKA J., ZLOCHA M., IVERSON L. Modelling topographic potential for erosion and deposition using GIS. Int J GIS **10**, (5), 629, **1996**.
24. WU S., LI J., HUANG G., An evaluation of grid size uncertainty in empirical soil loss modeling with digital elevation models, Department of Agriculture, Regina, Saskatchewan, Canada. Environ Model Assess, **10**, (1), 33, **2005**.
25. GAVRILOVIĆ S. Torrential flow engineering and erosion processes. Izgradnja, posebno izdanje, pp. 292, **1972** [In Serbian].