ASSESSMENT OF SOIL EROSION POTENTIAL USING RUSLE AND GIS: A CASE STUDY OF BOSNIA AND HERZEGOVINA

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ABSTRACT

Soil erosion is a significant environmental problem that causes severe consequences on the human society and economy. The Integrated Revised Universal Soil Loss Equation (RUSLE) with the Geographic Information System (GIS) have been used to assess the potential of soil erosion in the northern part of Bosnia and Herzegovina. An average of 9.88 t ha-1year-1 of potential soil erosion was estimated in the study area, and 47.44% of the study area had an erosion rate of <2 t ha-1 year-1. The soil loss estimation of 2 to 10 t ha-1 year-1 is found in 22.92% of the territory. The estimation of soil loss of >10 t ha-1 year-1 is inherent in 29.63% of the study area. The results of this study can be used for planning of conservation practices and land-use planning, as well as a framework for evaluation of soil erosion factors in other local communities in Bosnia and Herzegovina, in the case when limited data are available.

KEYWORDS: Erosion potential, erosion rate, RUSLE, GIS, Bosnia and Herzegovina

1. INTRODUCTION

Soil erosion phenomena present a serious environmental problem causing soil degradation and water pollution around the world. As a natural process, it is greatly accelerated by anthropogenic activity [1-4]. Numerous models for estimation of soil erosion rate have been developed [5-14]. However, the Universal Soil Loss Equation (USLE) [5], later modified and defined as the Revised Universal Soil Loss Equation (RUSLE) [15], has been the most wide spread model used for prediction of soil erosion loss. In the Republic of Srpska, the intensity of erosion processes has been traditionally estimated using the Erosion Potential Method (EPM) [16], commonly used in countries originating from the former Yugoslavia [17-18]. In response to the widespread use of empirical models in conducting (the project entitled "Studies of the base of usage and protection of agricultural land of Republic of Srpska", funded by Ministry of Agriculture, Forestry and Water management in the Republic of Srpska), the USLE model was applied using the preliminary estimated input factors (R, K, LS, C, P) [19]. In this research, assessment of soil erosion potential was estimated using the RUSLE in conjuction with the GIS. This combined approach has been used in numerous studies [19-30] which report its several advantages, including ease of capturing, managing, analyzing, and displaying all results that are the most appropriate for practice purposes.

The objective of this paper is to assess soil erosion potential in the northern part of Bosnia and Herzegovina using the RUSLE together with the GIS. This combined approach has potential to support design of conservation practices, measures for erosion control, management of agricultural resources, and land use planning.

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2. MATERIALS AND METHODS

2.1 Study area

The study area located in the northern part of Bosnia and Herzegovina (Fig. 1) covers the area of 1256.07 km^2, with approximately 226,450 inhabitants. This area belongs to the large morphologic cluster called Panonic region. Based on litologic criteria, the parent rocks present in the area include fluvial, torrential, and slope sediments, as well as flysch, neogene and mesozoic rocks. Quaternary surface sediments are indigenous rock mass of Neogene (marl clay, marl, sand, gravel, etc.), Cretaceous (limestones, marly limestones and breccias, etc.), and diabase-chert formation complex (serpentinite, cherts, diabase, dolomite, etc.) [31].

The terrain ranges from 139 to 1338 m above sea level, and has moderate continental climate, with an average annual temperature above 10 °C and rainfall of 1050 mm. There are two large rivers in the study area, Vrbas and Vrbanja. Soils dominant in this area are Planosols-pseudogley, Fluvisols, eutric, dystric and mollic Gleysols [32].

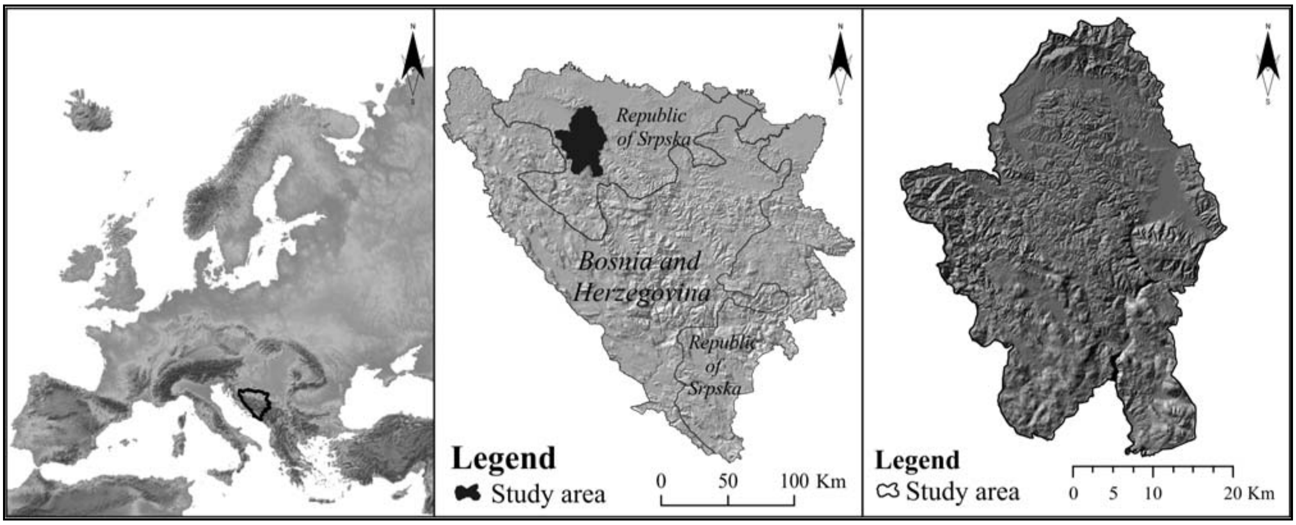

FIGURE 1 - Location of the study area.

2.2 Methods

The most common method used for prediction of average soil loss rate in agricultural lands is the USLE [5]. The USLE concept has been modified and adapted during the past 35 years by a large number of researchers [8-9, 15, 33-36]. Renard *et al.* (1997) [15] modified the equation into the Revised USLE (RUSLE) by introducing improved means of computing the soil erosion factors. The RUSLE has been extensively used to estimate soil erosion loss, assess soil erosion potential, and guide development and conservation practices in order to control erosion under different land use conditions. In this study, the RUSLE is combined with the ArcGIS to estimate average annual soil loss that occurs within the territory of study area. Integration of the RUSLE and the ArcGIS led to a more easier and efficient soil erosion prediction and spatial distribution of soil erosion. Each of the six factors was analyzed independently, and determined on raster cell basis. The spatial resolution of the data set is 20·20 m. The RUSLE computes soil erosion as the product of six factors including rainfall erosivity, soil erodibility, slope length and slope steepness, cover management practice, and support conservation practices [15]. The RUSLE can be expressed with the following equation:

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

where, A is average annual soil loss (t ha^{-1} y^{-1}), R is rainfall erosivity factor (MJ; mm ha^{-1} h^{-1} y^{-1}), K is soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1}), S is slope factor, L is slope length factor (dimensionless), C is cover management factor (dimensionless), and P is supporting practice factor (dimensionless).

Rainfall erosivity (the R-factor) is an important factor used in calculation of soil erosion by the USLE and the RUSLE [5, 15]. In the original formulation of the USLE [5], the R factor was calculated as the product of the total kinetic energy of the storm (E), and its maximum 30-min intensity (I_{30}). The calculation of the rain erosivity factor (R) is performed by the division of rain into segments, small time intervals of 5 to 10 min, of uniform intensity. Then, the kinetic energy (E) is calculated for each segment by the following equation:

$$E = 0.119 + 0.0873 \cdot \log_{10}(I) \quad \text{for } I \leq 76 \text{ mm h}^{-1} \quad (2)$$

$$E = 0.283 \quad \text{for } I > 76 \text{ mm h}^{-1} \quad (3)$$

where, E is the energy per unit of rainfall (MJ mm^{-1} ha^{-1}), and I is the rainfall intensity for each interval (mm h^{-1}). Multiplied by the rainfall during that segment, it gives the total kinetic energy of the segment. The sum of kinetic energies of all segments gives the total kinetic energy of the rain which, multiplied by the maximal 30-min intensity, gives the factor of the rain erosivity. The factor of rain erosivity is calculated based on the following equation:

$$R = E \cdot I_{30} / N \quad (4)$$

where, R is factor for single rain (MJ mm ha^{-1} h^{-1} y^{-1}), (EI_{30}) is EI_{30} for rainfall event i, and j is number of rainfall events in an N year period.

Rainfall events were documented from 2001 to 2011 by only one station, Banja Luka meteorological station. Having the data from only one source is not enough to ensure data reliability. Therefore, the erosivity index for other 14 stations in the vicinity of the study area was estimated using the data of precipitation, (monthly and annual rainfall).To date, there is no formal agreement on how to retrieve R. Each proposed method has been optimized for a certain territory and, therefore, is not necessarily applicable in other areas. In order to choose the most appropriate method for the area under study, several well-known methods have been tested [37-40]. Based on the results, the Renard and Freimund (1994; [39]) method was selected. An accordance with this method, the erosivity factor (R) is based on the modified Fournier Index (F) which takes into account average annual and monthly rainfall data and the empirical formulas to linked F to R.

$$F = \sum_{i=1}^{12} \frac{p_i^2}{P} \quad (5)$$

where, p_i is the monthly precipitation for month i (mm), and P is the annual precipitation (mm). Approximate R equations in Renard and Freimund [39] method are summarized as follows:

$$R = 0.739 \cdot F^{1.847} \quad (6)$$

Rainfall erosivity map of the study area was obtained by applying the Inverse Distance Weighting (IDW) deterministic interpolation method where values at ungauged points are calculated from known points using a weight function in a search neighborhood. Known values are used to determine unknown ones that are surrounding each data point [28, 41].

The soil erodibility factor K represents the average long-term soil response to the erosive power associated with rainfall and runoff. The main soil properties influencing K factor are soil texture, organic matter, soil structure and permeability of soil profile.

A survey with a total number of 119 soil profiles was administrated to determine the soil erodibility factor. Sample locations were carefully selected to be representative for each geology and soil unit in the study area. Only the top layers were used for the determination of soil erodibility factor value. The permeability class was obtained based on the soil texture data, while soil structure code was obtained from the soil profile description. In this study, the K value was computed using the Algebraic approximation of the nomograph where the Si fraction does not exceed 70% [5, 15]:

$$K = [2.8 \cdot 10^{-5} \cdot (12-OM) \cdot M^{1.14} + 4.3 \cdot 10^{-1} \cdot (S-2) + 3.3 \cdot 10^{-1} \cdot (P-3)]/100 \quad (7)$$

where, OM is percent organic matter (%), S is soil structure code, P is soil permeability class, M is particle size parameter (% silt + % very fine sand) (100 – % clay).

The values of computed soil erodibility factor (K) at the sampling points were used for prediction values at unknown points using the ordinary kriging interpolation method [42, 43]. The map of K factor was generated in the geostatistical tool of the ArcGIS using the variogram models and parameters to obtain a high quality map.

The LS factor was computed using the Digital Elevation Model (DEM) with the ArcGIS Spatial Analyst extension. The slope length factor (L) and slope degree factors (S) are typically combined together and defined as the topographic factor, which is the function of both the slope and length of the land [34, 44-49]. Herein, the LS values were computed as follows:

$$LS = \left(\frac{Fa \cdot Cs}{22.13}\right)^{0.4} \cdot \left(\frac{\sin s}{0.0896}\right)^{1.3} \quad (8)$$

where, the slope length is estimated from Flow accumulation (Fa), which is the number of cells contributing to flow into a given cell, cell size (Cs) and slope (s) is the slope steepness of the cells using the grid-based representation of the landscape-digital elevation model (DEM). In this study it was necessary to define maximal length of land, where we shall look for potential erosion. In this analysis, it was agreed that this length should be 100 m. That means, for our digital elevation model of 20 m cell size, a maximum value for flow accumulation will be presented in 5 cells.

The C factor is vegetation cover and crop management factor or the ratio of soil loss from area with specified cover and management. Crop management factor depends on vegetation cover, which dissipates the kinetic energy of the raindrops before impacting the soil surfaces. This is an important factor in the RUSLE, since it represents the conditions that can be changed to reduce erosion intensity [5, 15].

In this study, the C factor values were determined on a basis of the CORINE Land Cover B&H (2006) database on a scale of 1:100000 [50]. For the purpose of this study, the orthophoto image (year 2012) was ordered with a resolution of 10 m. Based on this data, changes in the CORINE Land Cover B&H database (2006) have been made for the area under study. Values of C factor have been attributed to all land-use types according to the values cited in literature [19, 25, 30, 51-53]. The study area was classified into 16 land use/cover classes (Table 1). A map of C factor was generated using ArcGIS tools through reclassification of each land-use type into its corresponding C values according to Table 1.

TABLE 1 - CORINE land use code and corresponding crop management factor (C).

CLC_code	Description	C factor
112	Discontinuous Urban Fabric	0
121	Industrial or Commercial	0
122	Road and Rail networks	0
131	Mineral extraction sites	0
211	Non - irrigated arable land	0.45
222	Fruit trees and berries plantation	0.25
231	Pastures	0.02
242	Complex cultivation	0.12
243	Land principally occupied by agriculture with significant areas of natural vegetation	0.12
311	Broad - leaved forest	0.004
312	Coniferous forest	0.004
313	Mixed forest	0.004
321	Natural grassland	0.05
324	Transitional woodland scrubs	0.007
511	Stream courses	0
512	Water bodies	0

The P factor is the conservation practice factor, which is the ratio of the soil loss from a field, under given conservation support practice [5, 15]. Due to the fact there were no erosion control practices in the study area, P factor was assumed to be a unit value P = 1.

3. RESULTS AND DISCUSSIONS

In the study area, values of rainfall erosivity factor (R) were within the range 1288.01 – 1431.02, with the mean of 1353.34 MJ mm ha^{-1} h^{-1} y^{-1}. The R value is lowest within the central and north part of the study area, whereas mountainous southwest and southeast area had a higher value (Fig. 2). High values of R factor were also detected in the south part of the study area which had the highest monthly precipitation. However, it should be noted that erosion potential of this factor and its spatial distribution fluctuate due to pluviometric regime.

The value of soil erodibility factor (K) was within the range of 0.0041 – 0.0674, with the mean of 0.0357 t ha h ha^{-1} MJ^{-1} mm^{-1}. The map of K factor indicates that higher values of K factor are found in the north and northwest, while lower values are common in south, eastern and southeastern part of study area (Fig. 3), which could be caused by the soil texture or percentage of sand in the soils. Soils with higher percentage of sand and silt, developed on siliceous parent material, such as cherts, sandstone, etc., are characterized with higher sensitivity to erosion compared to soils with heavier (clay) texture developed on the rocks with a smaller percentage of quartz (clays, limestone, marl, etc.). Silicate parent material dominates on the central and northern part of the area under study, while the southern part is covered prevalently with limestone. Except soil texture and parent material, land-use is another important factor. Intensive agriculture and urbanization are present in the central part of the study area. These practices often result in degradation of physical soil properties (primarily structure), and reducing the amount of humus, which inevitably increase soil erodibility and the value of soil erodibility factor in the same time. One should keep in mind that southern and southeastern part of the area under study is mountainous, with mainly higher altitudes and under forest vegetation.

These soils are better structured, with a higher content of humus and a better water-air regime, which could lead to a smaller value of soil erodibility factor.

The LS factor was within the range 0 – 40.4692 with an average value 4.6359 in the study area. Spatial variability analysis shows that low values are characteristic for central and north part, while mountainous parts (south, south-western, eastern) of the area have high average values of this factor (Fig. 4). The southern, south-west and eastern section of the study area show the highest variability in elevation, steepest and longer slopes. River Vrbas and its tributaries have built gorges and canyons, and significantly dissected terrain in this part of the study area. As a consequence, there is a high level of LS factor. In the north, north-west, and central part of the area, the slopes are lesser. Flat terrain of the karst plateau Manjaca in south-west part and plains on north and north-west have contributed to low average values of LS factor.

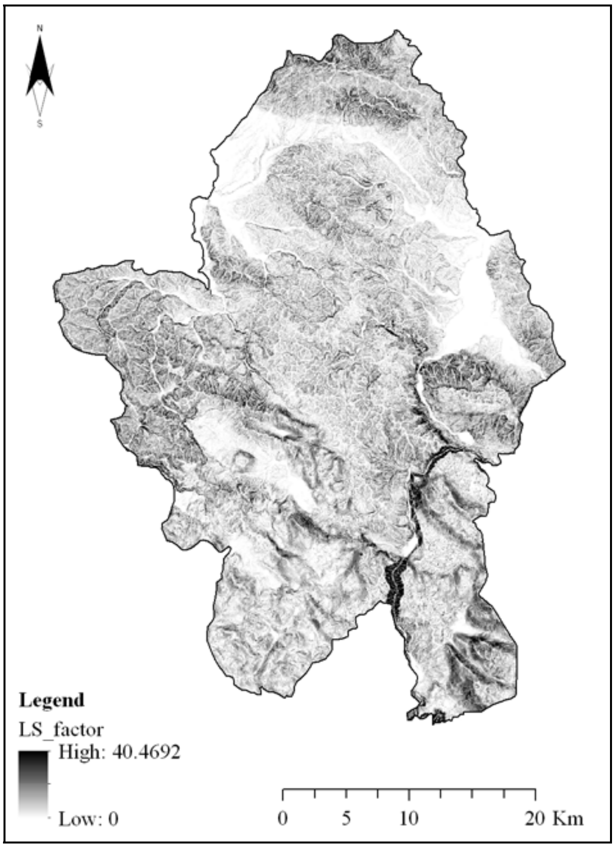

FIGURE 2 - Spatial distribution of R factor

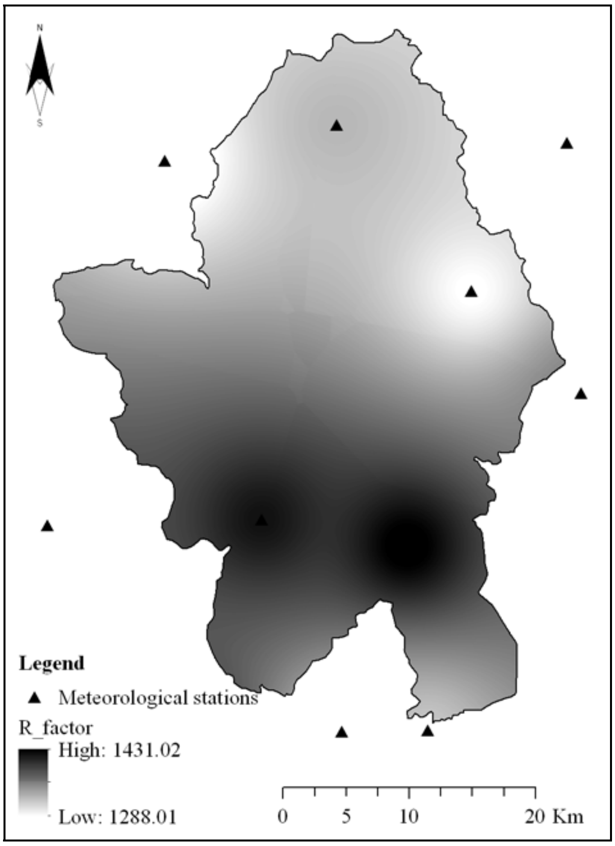

FIGURE 3 - Spatial distribution of K factor.

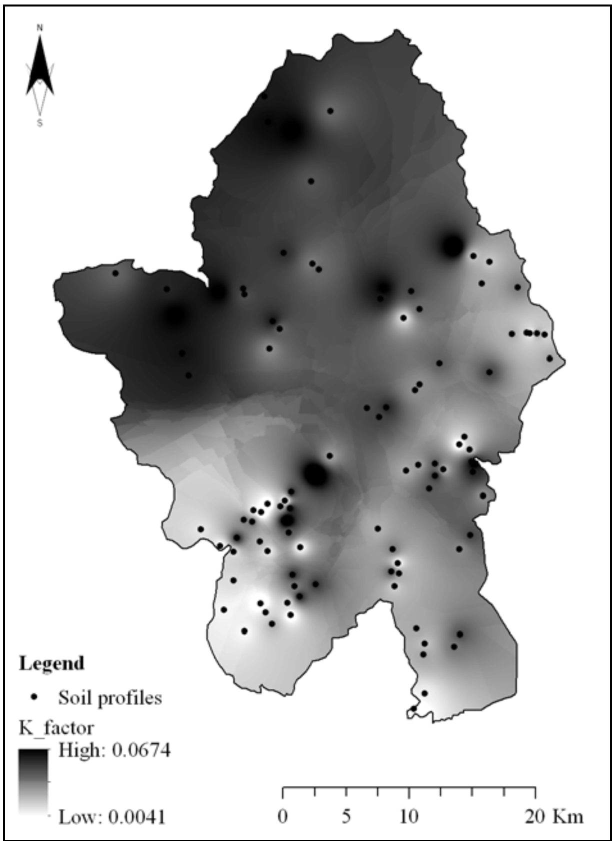

FIGURE 4 - Spatial distribution of LS factor.

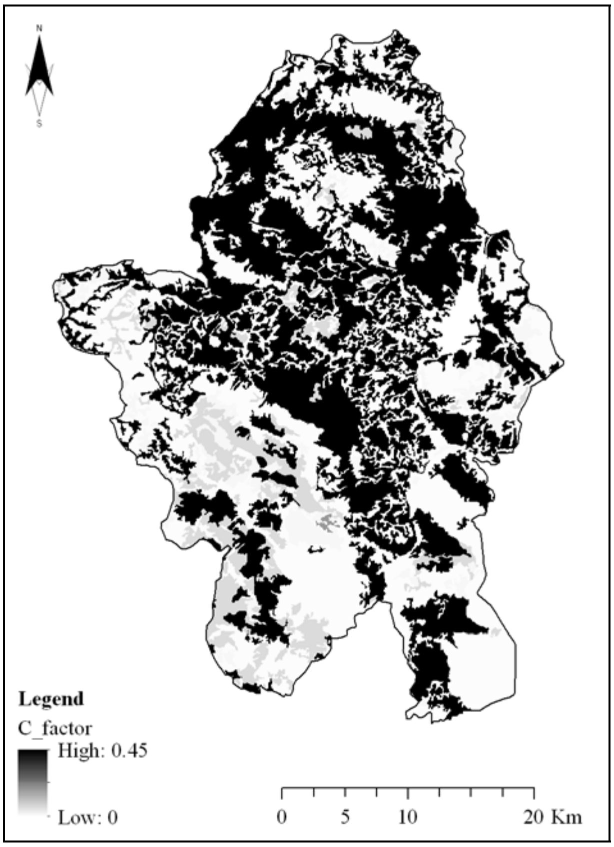

FIGURE 5 - Spatial distribution of C factor.

The values of crop management factor (C) range between 0–0.45. Spatial distribution of C-factor is quite heterogeneous. The study area is composed of 16 land use/ cover classes, where only 10 have the importance for soil erosion, including non-irrigated arable land (0.62%), fruit trees and berries plantation (0.12%), pastures (7.44%), complex cultivation (33.51%), land principally occupied by agriculture with significant areas of natural vegetation (11.62%), broad-leaved forest (37.29%), coniferous forest (0.40%), mixed forest (2.06%), natural grassland (0.07%), and transitional woodland shrubs (4.48%). However, it should be noted that 45.75% of the area is cultivated land and economically active. The high values of C-factor are determined in the central and southern part of the area under study, especially in the karst fields and flat plains-areas with intense agricultural activities.

Low values are measured under forest, pasture and meadow (Fig. 5). The average annual soil loss (A) in the study area was computed by overlaying the five maps using the RUSLE coupled with the ArcGIS.

Table 2 and Fig. 6 show the average annual soil loss (A) between 2 and 40 t $ha^{-1}year^{-1}$ in majority of study area, with an average value of 9.88 t $ha^{-1}year^{-1}$. The results indicate that more than 47.44% of the study area is under very low erosion, and 22.92% territory is being under low erosion. Moderate erosion was estimated on almost 11.39% of the study area. High erosion ranges from 20 to 40 t ha^{-1} $year^{-1}$, and occurs on 12.35% of the area. Very high erosion (higher than 40 t ha^{-1} $year^{-1}$) occurs at 5.88% of the area under study. Very low erosion (<2 t $ha^{-1}y^{-1}$) affects nearly 47%, prevalently northeastern and southern parts of the study area. Brown soils (eutric cambisol, dystric cambisol and calco cambisol) and leached soils are dominant in the northeastern part. Generally, those are well-structured forest soils, with high content of humus and under forest vegetation protection. Similar condition has been discovered in the southern part of the area, covered by limestone and dolomites, where typical limestone soil types are developed (black soil, rendzina, brown soil and ilimerized soil). Positive characteristics, such as structure, water and air regime, texture and high humus content, make these types of soil less erodible under such way of land-use (forest vegetation), which results in smaller values of soil erosion.

High erosion (occurs on 12.35%) and very high erosion (5.88%) were found mostly in the central part of the study area, but also on the very gentle slopes suitable for agricultural production. Soils in this part of the area are generally deeper and with higher clay content. However, due to their intensive use, their physical properties are deteriorated and erodibility is increased. Agricultural production requires mechanical tillage and application of fertilizers, pesticides and herbicides, which leads to a deterioration of structure, humus content, water and air regime. A very high value of erosion is caused by the disturbance of soil properties, and the way this resource is being used. The results obtained in this study are compared with the Erosion map of the Republic of Srpska [16, 54]. The values of soil erosion from this map match the values discovered in our study area. The soil erosion in study area is associated with different zones of elevation. Nearly 88.74% of the

TABLE 2 - Categories of rate of soil erosion in the study area.

Erosion categories	Rate of erosion (t ha^{-1} year^{-1})	Area (ha)	Area (km^2)	Area (%)
Very low	< 2	59588.84	595.8884	47.4403
Low	2 – 10	28791.88	287.9188	22.9220
Moderate	10 – 20	14312.32	143.1232	11.3944
High	20 – 40	15519.08	155.1908	12.3552
Very high	> 40	7395.84	73.9584	5.8880
		125607.96	1256.0796	100.00

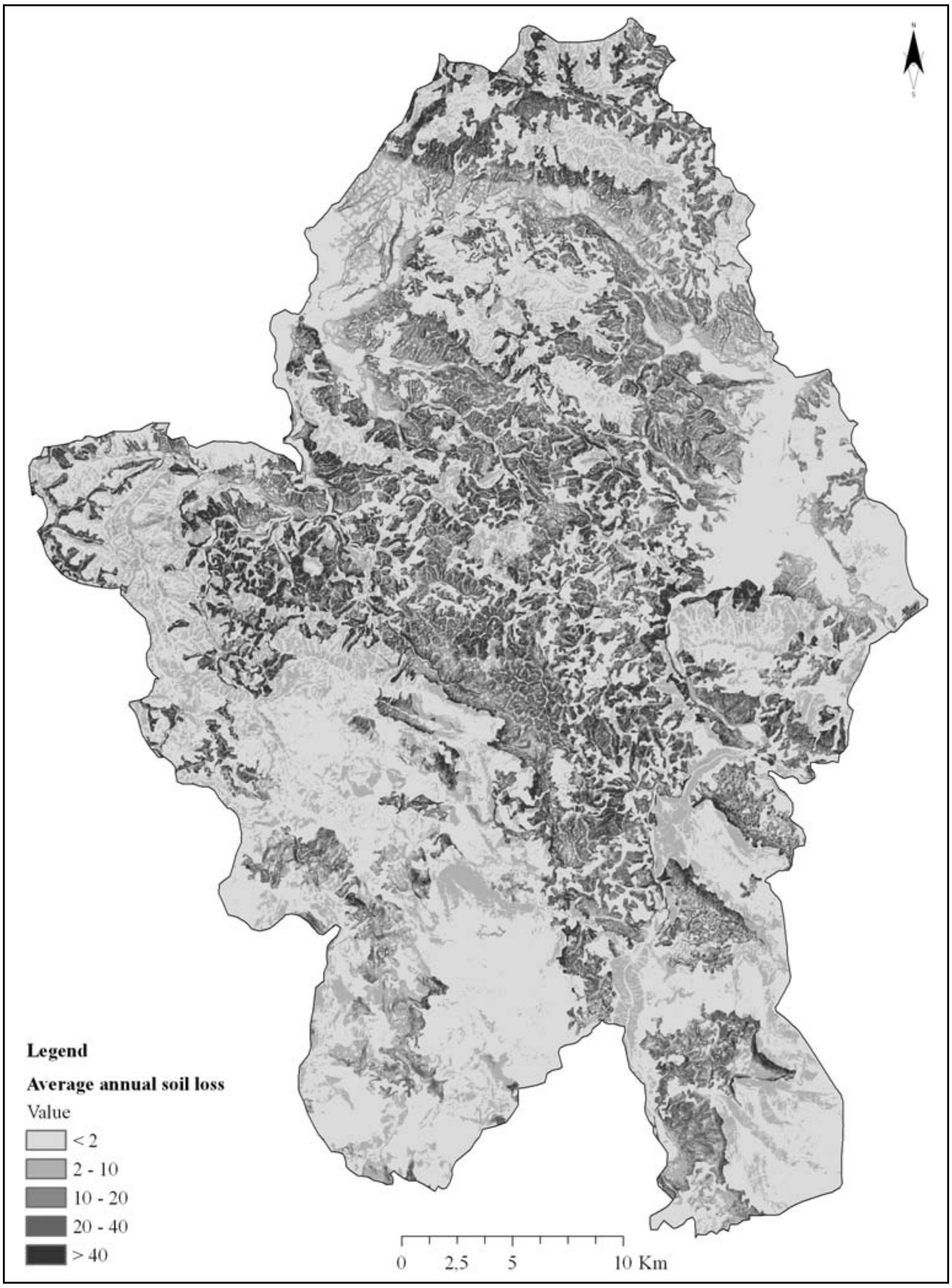

FIGURE 6 - Map of average annual soil loss rate in the study area according to RUSLE.

TABLE 3 - Percentage of soil erosion category under different elevation zones.

Elevation	Soil erosion categories and rate of soil erosion (t ha^{-1} year^{-1})					Total
	Very Low	Low	Moderate	High	Very high	
	< 2	2 – 10	10 – 20	20 – 40	> 40	
0 – 200	65.07	21.10	8.49	4.24	1.11	100.00
200 – 500	37.74	22.96	14.48	16.76	8.06	100.00
500 – 1000	58.53	24.62	6.91	6.66	3.29	100.00
> 1000	87.65	11.44	0.37	0.41	0.12	100.00

TABLE 4 - Percentage of soil erosion category under different land use types.

Land use types	Soil erosion categories and rate of soil erosion (t ha^{-1} year^{-1})					Total
	Very Low	Low	Moderate	High	Very high	
	< 2	2 – 10	10 – 20	20 – 40	> 40	
Arable land	14.13	22.55	24.14	26.58	12.59	100.00
Forestland	79.49	20.51	0.00	0.00	0.00	100.00
Orchards	21.63	35.62	22.90	14.96	4.89	100.00
Grasslands	51.74	45.26	2.70	0.23	0.07	100.00

erosion occurred in the zone between 200 and 1000 m, which is closely related to topographical characteristics and use of land.

The elevation from 200 to 500 m is an agricultural region (Table 3). The elevations from 500 to 1000 m represent a mixed region which is prevalently under orchard, pastures and natural grassland. Nevertheless, more than 34% of high and very high soil loss occurs in the area between 200 and 1000 m. For that reason, specific conversation measures used to reduce soil loss have to be designed and applied. The soil erosion map was overlaid with land use map, and distribution of erosion categories under different land use types was analyzed. Results show that 63.31% of the arable land is under moderate, high and very high soil erosion, while high values of soil loss are expressed under orchards (Table 4). Nearly 100% of grasslands have low and very low soil erosion, while forestlands do not have moderate, high, and very high soil erosion.

Forestland and grasslands have a great impact on reduction of soil erosion. However, results show that the arable land and orchard are priority areas where soil conservation measures should be implemented in future.

4. CONCLUSION

There are numerous models for assessment of soil erosion. Empirical models are frequently prefered over complex physically-based models that could be implemented in situations with limited data and parameter inputs, for example in the Bosnia and Herzegovina. The RUSLE model, which is identified as appropriate to be applied within the GIS framework, to develop and apply a simple methodology for preliminary mapping of soil erosion, is a good example.

In addition to describing the character of the soil loss process, the results yielded in this research also provide an insight into spatial distribution of this process on the territory of the study area. Average annual soil erosion rate obtained in the study area is 9.88 t ha^{-1}year^{-1}. More than 47.44% of the study area is under very low erosion, while 22.92% of the territory is under low erosion. Moderate erosion is close to 11.39 %, high erosion ranges between 20-40 t ha^{-1} year^{-1}, and occurs on 12.35 % while very high erosion rates,>40 t ha^{-1} year^{-1}, occur at 5.88 % of the study area. Furthermore, the results indicate that more than 34% of the area with high and very high soil loss occurs in the elevation between 200 and 1000 m, with arable land and orchard where soil conservation measures should be implemented to reduce soil loss.

However, to promote usage of this combined approach, the results obtained by using the RUSLE and the GIS need to be confirmed and validated. An overlap of the results from this study with the results of the Erosion map of Republic of Srpska will encourage future use of the RUSLE model in this region, especially when there is a need to evoke studies and calculation of soil erosion as a support for the implementation of soil conservation programs, sustainable agricultural exploitation and environmental protection. In the future, to provide more accurate results of the RUSLE prediction, direct field measurement of soil erosion in the Bosnia and Herzegovina needs to be obtained.

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