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SOIL EROSION MODELLING IN THE COMPLEX TERRAIN OF PIROT MUNICIPALITY

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Abstract: This paper aims at assessment of soil erosion potential and its spatial distribution on the 1235 km^2 area of municipality Pirot located in south-eastern Serbia. The study was conducted by using well-known Universal Soil Loss Equation (USLE) model due to its modest data demand and transparent structure. The erosion factors of USLE were collected and processed through a GIS-based approach offering ease of elaboration and manipulation of erosive factors. All the erosive factors were determined on a 30 x 30 m cell basis and multiplied in order to obtain the map of potential average annual soil erosion. The average annual soil loss was estimated at 8.65 $tha^{-1}yr^{-1}$ classifying the area of Pirot municipality under low erosion rate category. More than 80% of the municipality area was characterized by insignificant (< 3 $tha^{-1}yr^{-1}$), and low erosion category (3-10 $tha^{-1}yr^{-1}$). Around 7.8% of the area was found to be under moderate erosion category (10-20 $tha^{-1}yr^{-1}$). High erosion category was found on 6.8% of the area (20-40 tha^{-1} yr^{-1}), while there is around 5.2% of the area under very high erosion category (>40 $tha^{-1}yr^{-1}$). It means that almost 15000 ha of the area of Pirot municipality are facing high and very high erosion. The analysis of vertical distribution of erosion processes pointed out that the zone between 500 and 800 m a.s.l suffers more from erosion than other elevation zones mainly due to land management. The results of this work are in agreement with the soil erosion map of Serbia, the sediment yield measurements in the basin and with other, more detailed, studies in the municipality. Therefore, the presented methodology could be applied as a framework for the evaluation of erosive factors on soil resources in Serbia when limited data are available. The outputs of these studies can be used for the identification of vulnerable areas on a cell-basis and for programming of protection measures.

Keywords: USLE, GIS, Erosion, CORINE, Elevation zones Serbia

1. INTRODUCTION

Soil erosion is one of the major causes of land degradation in Serbia. Problems caused by erosion are resulting in economic loss in agriculture and forestry sector, and may directly or indirectly pose a danger to persons or property. Prediction of erosion soil loss is important for the assessment of erosion risk and for the implementation of appropriate measures of land conservation. Nowadays, there is a number of erosion models that are empirically or physically based. Universal soil loss equation (USLE) is an empirical model developed by Wischmeier & Smith (1978) and it is a worldwide accepted method despite some limitations. In the municipality of Pirot USLE method was not used before. Inspite of this, Gavrilović model (1972) was used and some detailed studies on water erosion potential in Pirot district were conducted on smaller watersheds and tributaries of the River Nišava (Kostadinov 2003a, 2003b; Mustafić, 2008). Integration of USLE and GIS has led to a more easier and efficient soil erosion prediction and spatial distribution of soil erosion. There is a huge number of studies conducted with USLE through GIS environment (Lee 2004; Irvem et al. 2007; Dabral et al., 2008) on the different locations in the world. The advantages of GIS tools in USLE methodology are related to determination of topographic factor from DEM, use of geostatistics and to of remote sensing in determination of cover management factor. This work aims at determining potential soil erosion in municipality of Pirot by the use of USLE methodology through GIS.

2. STUDY AREA

The municipality of Pirot is located in the South-Eastern Serbia on the border zone with Bulgaria between 22° 36' east longitude and 43° 09' north latitude (Figure 1). The municipality is surrounded by Old Mountain on the north and north-east, mountain Vidlič on south-east, Vlaška Mountain on the south, while the west and north-west border rich to Svrljiške Mountain. In 2002, Pirot had a total population of 40678 inhabitants, while the population of the municipality was 63791. Rural population settles 71 villages in the municipality. Average population density is 52 inhabitants per km^2. Total area of the municipality is 1235 km^2 and it is one of the biggest in Serbia. The complexity of landscape in the municipality Pirot is well noticed through the difference in elevation. Elevation ranges from 368 m to 2169 m on Old Mountain, Midžor.

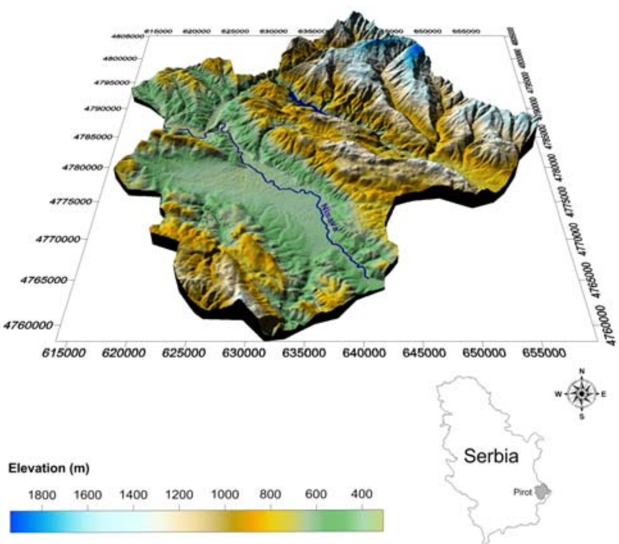

Figure 1. Geographic location of the study area

The area is characterized by hilly-mountainous relief in the most of the municipalty, and alluvial plane downstream and around the River Nišava water course. The Nišava flows from south-east to north-west direction and it is characterized with high water level fluctuations and with very developed hydrographic network. The main tributaries of the River Nišava on the territory of Pirot municipality are: the Jerma, the Temska, the Visočica, the River Dojkinačka and other smaller tributaries. There are three lakes in the municipality: Zavojsko, Krupačko and Sukovsko lake. Average maximum annual temperature in the municipality is 18.4^0C average minimum annual temperature is 5.9^0C, while average rainfall measured in the 60 year period is 584.8 mm. The agriculture production faced de-intensification in the last two decades due to severe migration to urban areas and it is characterized with small farming systems.

3. METHODOLOGY

The methodology applied is based on the use of USLE model in GIS in order to provide the spatial distribution of the results over the whole watershed and to identify the areas particularly affected by erosion risk. Input data belong to historical weather datasets, soil maps, digital elevation model (DEM), and land cover derived from Corine Land Classes.

USLE model (Wischmeier & Smith, 1978) was originally developed to estimate average annual soil loss and its spatial distribution for given natural and anthropogenic conditions. 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 (Wischmeier & Smith 1978). The model determines average annual soil erosion as the product of six erosion factors (Eq. 1).

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

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 (-), C - crop management factor (-), and P - conservation supporting practice factor (-), set to one in this study because we assumed no conservation measures were conducted in the study area.

Each factor was independently analysed and determined on raster cell basis. Calculations were performed in the 30 x 30 meters cell resolution which has advantages to identify areas under high erosion risk. Although the original model was developed for agricultural areas with slopes from 3% to 18%, its successful use in hilly and mountain regions was reported (Dabral et al., 2008; Irvem et al., 2007; Kim et al., 2005; Millward & Mersey 1999; Zhou et al., 2008).

3.1. Rainfall Erosivity Factor (R)

Determination of R factor in the study area was done using historical weather datasets from Pirot and Topli Do meteorological stations which are located in the study area, and from other 16 meteorological stations in and aroud the River Nišava water basin. The lack of dense meteorological network and fine rain intensity measurements made us use simplified model GJRM to obtian R values. Grimm et al., (2003) adopted simple algorithm proposing that erosivity in Tuskany region in Italy is proportional to annual rainfall. In this study mean annual rainfall from 60 years period (1949-2008) were used to obtain average R values for the meteorological stations. In this model R-factor is a function of the mean annual rainfall (mm):

$$R=b_0\,P_m \quad (2)$$

Where: R – Rainfall erosivity (MJ mm h^{-1} ha^{-1} $month^{-1}$); P_m is the mean annual rainfall (mm); b_0 – empirical coefficient (MJ h^{-1} $month^{-1}$), which has values from 1.1-1.5, and it was adopted to be 1.3 by Grimm et al., (2003) and used in our study.

Geostatistical interpolation allows one to account for the spatial dependence between observations in the prediction of attribute values. USLE application with the support of geostatistical techniques has received special attention by researchers (Irvem et al., 2007; Pandey et al., 2007; Ozcan et al., 2008). Prediction map of the R factor (Fig. 2) was created from the annual erosivity values using ordinary kriging. Ordinary kriging is very convenient as a prediction technique because of simplicity and reliability. This technique allows prediction of an unsampled location based on neighbouring data values.

Rainfall erosivity factor values on the territory of Pirot municipality ranges from 862.3 MJ mm h^{-1} ha^{-1} $month^{-1}$ around town of Pirot to 937.2 MJ mm h^{-1} $ha^{-1}month^{-1}$ around Topli Do station in the mountainous area of municipality.

3.2. Soil Erodibility (K)

The 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 it represents a function of intrinsic soil properties. The main soil properties influencing K-factor are soil texture, organic matter, soil structure and permeability of soil profile. In this study K value was computed by equation of Wischmeier & Smith (1978):

$$K=2.8x10^{-7}M^{1.14}(12-a)+4.3x10^{-3}(b-2)+3.3x10\text{-}3(c\text{-}3) \quad (3)$$

Where: K - Soil erodibility factor in t ha h ha^{-1} MJ^{-1} mm^{-1}, M - particle size parameter (% silt + % very fine sand)*(100 - % clay), OM – organic matter (%), s – soil structure code, p – soil permeability class.

In this study, the K values were computed using Eq. 3 and multiply by 0.1317 to convert to SI units, and a soil map of the River Nišava basin in the scale 1:50000. A survey with total number of 174 soil profiles were used to create a soil map of the study area, and the existing data on soil profiles were used to determine soil erodibility. Only top layers were used for the determination of K value. The permeability class was obtained on basis of data for soil texture, while soil structure code was obtained from soil profile description. Soil cover in the area is very heterogeneous and it consists of 13 different reference soil types according to ex-Yugoslavian classification system (Škorić et al., 1985). The spatial distribution of soil erodibility is given in figure 2.

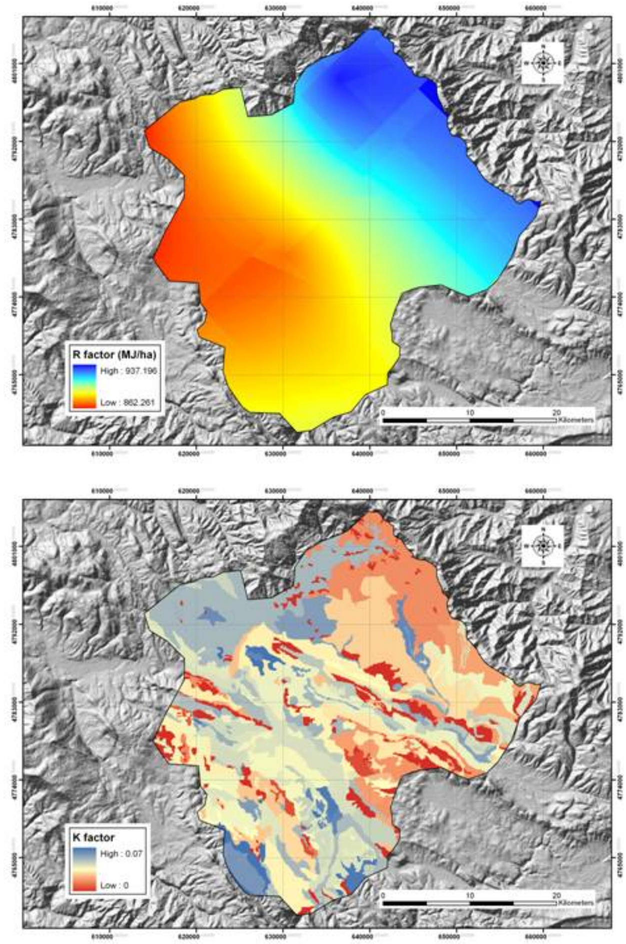

Figure 2. Spatial distribution of R and K factor

In the table 1 values of soil erodibility for the different soil types of ex-Yugoslavian classification system are presented. The obtained values are well related to those reported in the literature (Vopravil, 2007). The highest values of soil erodibility factor were found in Pseudogley, Luvisol and Gleysoil, while the smallest values of erodibility were obtained in mountainous soils, both calcareous and non-calcareous, Ranker, Kalkomelanosol and Calcic Cambisol.

Table 1. Dominant soil types in Pirot municipality and basic statistics related to soil erodibility factor

Soil types	No of profiles	Avg	Stdev	Median
Regosol	9	0.0383	0.0129	0.0357
Gleysol	4	0.0415	0.019	0.0344
Calcic Cambisol	10	0.0262	0.0039	0.0267
Dystric Cambisol	18	0.0379	0.0103	0.0382
Rendzic Leptosol	33	0.0287	0.0075	0.0292
Ranker	40	0.0205	0.0102	0.0169
Pseudogley and Luvisol	10	0.0444	0.01	0.0436
Vertisol	20	0.0318	0.0062	0.0307
Fluvisol	8	0.0388	0.0063	0.0396
Eutric Cambisol	14	0.0373	0.0078	0.0344
Kalkomelanosol	8	0.0261	0.0047	0.0253

3.3. Topographic factor (LS)

This factor includes two components, the slope length factor (L) and the slope steepness factor (S). The slope length factor represents the effect of slope length on erosion, and the slope steepness factor reflects the influence of slope gradient on erosion. The basic input for generating LS factor grid in GIS was 30 m DEM dataset. The L-factor was calculated based on the relationship developed by McCool et al., (1987). The equation follows as:

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

Where:λ is the horizontal projected slope length, m is the slope length exponent.

The S-factor was calculated based on the relationship given by McCool et al. (1987):

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

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

Where: θ - slope angle (^{0})

LS factor was calculated in a program that automatically calculates the value of this factor. The automated techniques are faster and provide more precise and reproducible measurements than traditional manual techniques applied to topographic maps. Digital data generated by automated techniques also have the advantage that they can be readily imported and analyzed by GIS. The program was originally written in Arc Macro Language (AML) (Hickey et al., 1994; Hickey, 2000) and has been updated in 2004 with the C++ programming language to be more efficient in processing (Van Remortel et al., 2004). The spatial distribution of LS factor is given in figure 3.

3.4. Cover management factor (C)

The C factor expresses the influence of the type of the land use (crop and natural vegetation) on the erosion processes (Arghiuis and Arghius 2011). The values of cover management factor depend on land use. In this study C factor was determined on a basis of CORINE Land Cover (1992) database on a scale of 1:100000. The municipality of Pirot area was classified into 18 land cover classes (Table 2). For each land cover class a corresponding C factor value was assigned using values given in the literature (Bathrellos et al., 2010; Lastoria et al., 2010; Sivertun & Prange, 2003). The spatial distribution of C factor is given in figure 3.

Table 2. Cover management factor values assigned to CORINE land cover classes on a basis of values found in the literature (see above)

CLC code	Description	C Factor
111	Continuous urban areas	0
112	Discontinuous urban areas	0
121	Industrial or commercial areas	0
211	Non-irrigated arable land	0.4
221	Vineyards	0.35
231	Pastures	0.02
242	Complex cultivation patterns	0.17
243	Land principally occupied by agriculture, with significant areas of natural vegetation	0.2
311	Broad-leaved forest	0.005
312	Coniferous forest	0.004
313	Mixed forest	0.005
321	Natural grasslands	0.05
324	Transitional woodland-shrub	0.009
331	Beaches, dunes, sand plains	0.3
332	Bare rock	0
333	Sparsely vegetated areas	0.35
511	Water streams	0
512	Water bodies	0

4. RESULTS AND DISCUSSION

Finally, after the production of above described raster files for the erosive factors USLE model could be implemented. This was done by simple multiplication of obtained raster files and the result is a map of potential soil loss for each pixel of 30 x 30 m resolution.

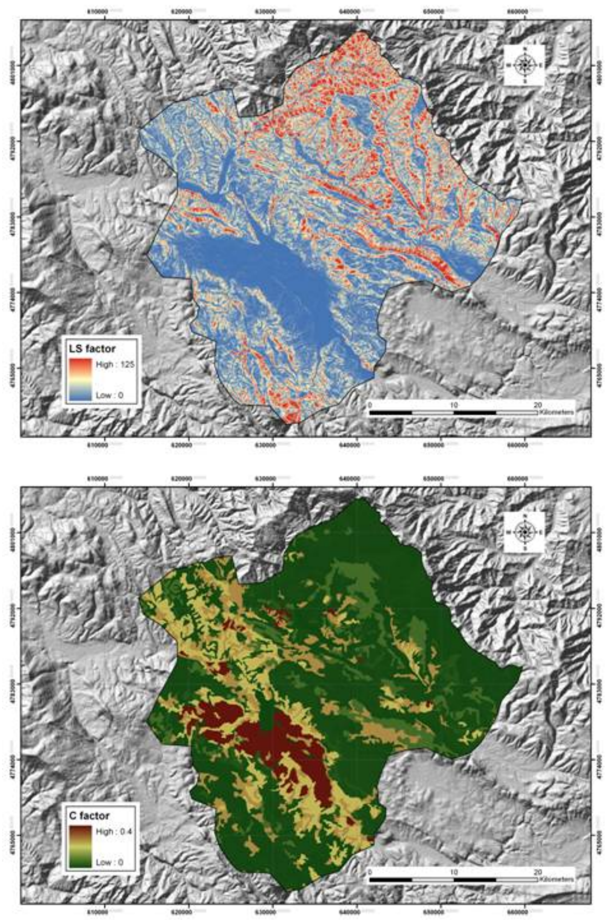

Figure 3. Spatial distribution of LS and C factor

In figure 4 spatial distribution of the average annual soil loss potential (A) in tons per acre per year in Pirot municipality is presented.

Quantification of the soil erosion potential in this work was not done by the use of Serbian quantification of erosion categories due to the fact that they do not exist expressed in tha^{-1}year^{-1}. Therefore, the quantification of surface erosion process in the Pirot municipality was done according to the recommendations of the Romanian legislation as presented in Arghiuis & Arghius (2011). This classification of soil erosion risk does not include gully erosion and landslides. Encouragement for us was to use bordering country classification because all the previous classifications in Serbia referred to Gavrilovic's erosion coefficient and the correlation of this coefficient to tha^{-1}year^{-1} has not been found yet. The results of average potential annual soil loss are presented in table 3.

The results indicate that more than 60% of the municipality is under insignificant erosion and that more than 80% of municipality of Pirot is under significant and low erosion. Moderate erosion is on almost 8% of municipality area, or on 96.1 km^2. High erosion, which ranges from 20 to 40 t ha^{-1} year$^{-1,}$ occurs at 84.9 km^2, or on 6.8% of the area. Very high erosion rates, higher than 40 t ha^{-1} year^{-1}, occur at 64.8 km^2, or at 5.2% of the territory. Totally, the last two classes cover 12% of the municipality, or expressed in the unit of area, 149.7 km^2, or 14970 hectares.

Table 3. Erosion categories in Pirot municipality and the area under each erosion category

The erodibility classes (t ha^{-1} yr^{-1})		Area (km^2)	Area (%)
Insignificant	< 3	746.3	60.5
Low	3-10	242.9	19.7
Moderate	10-20	96.1	7.8
High	20-40	84.9	6.8
Very high	>40	64.8	5.2
Total		1235	100

The average annual soil erosion potential for the municipality Pirot is 8.65 tha^{-1}year^{-1} allocating it to low erosion category. Unfortunately, averaging the spatial result is not very promising. The erosion process is very complex and if it is not considered seriously it could be easily widespread due to surface runoff, which is an important factor at hilly mountainous and sloppy terrain.

Therefore, the next part of our analysis was related to the spatial distribution of soil erosion categories (Table 4). The results presented in table 4 indicate that only 4% of municipality area is at elevations higher than 1500 m, and that there is insignificant or low erosion on these altitudes, with only 0.1% of the total area covered by moderate erosion (around 125 ha). This is due to the fact that these areas are covered by dense forest and soils such as Rankers and Kalkomelanosols, known by its low erodibility values are covering mountain peaks and high elevations. Somehow higher erosion intensity values are found in the area with elevation ranging from 1200-1500 m which occupies 11% of total municipality area. In this elevation zone more than 90% of erosion belongs to insignificant or low category.

The elevation zone up to 500 m a.s.l is located mainly at the River Nišava valley, and at the valleys of the River Nišava tributaries. In this zone the agricultural production is the most intensive and dominant erosion categories are insignificant and low erosion, with around 1235 ha of very high and 2100 ha of high erosion. Elevation zones between 500 and 1200 m cover 66% of the total area. In the 500-800 m a.s.l. small farming systems agricultural production is still found and this is the zone which suffers from the highest erosion rates, which is also reported in study of Mustafić et al. (2008) conducted on the part of Pirot municipality, in Visočica catchment, with Gavrilović method.

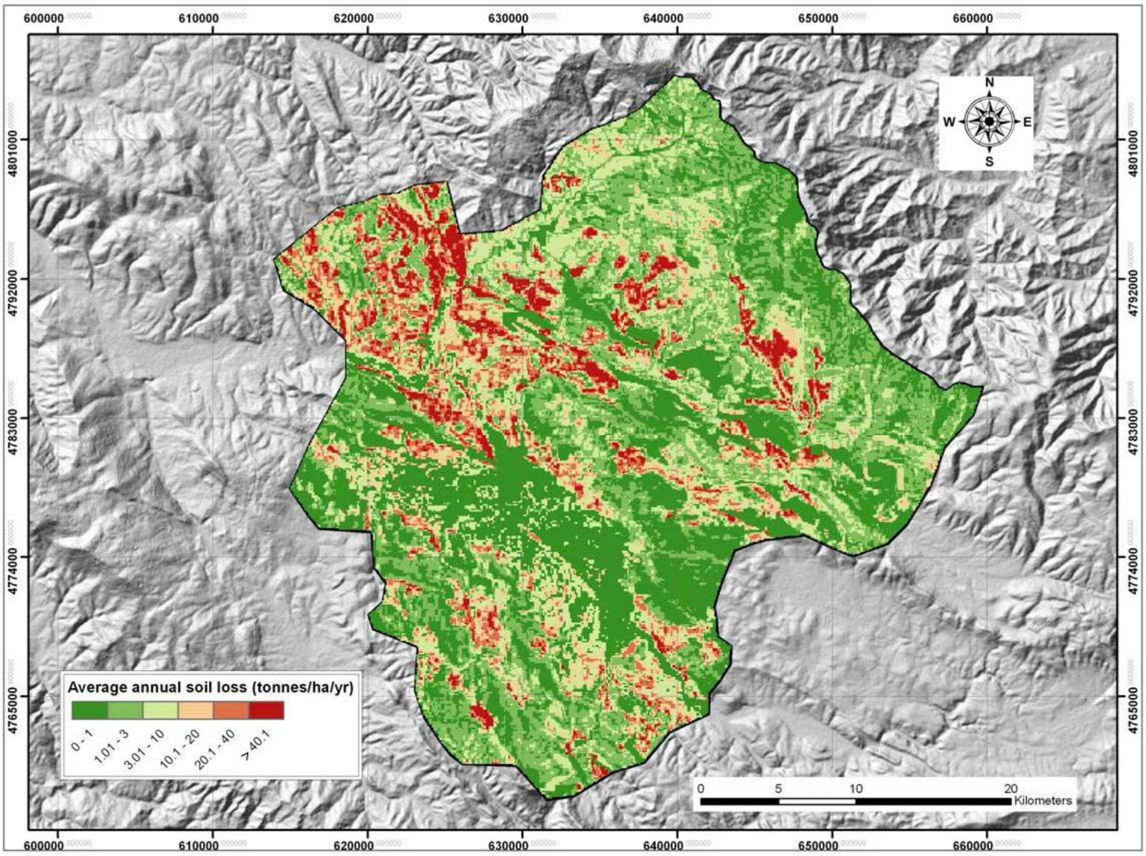

Figure 4. Spatial distribution of potential average annual soil loss ($tha^{-1}year^{-1}$) in Pirot municipality

Table 4. Percentage of soil erosion cateegory under different elevation zones

Elevation zones (m)	The erodibility classes (t ha-1 yr-1)					Total
	Insignificant	Low	Moderate	High	Very high	
	<3	3-10	10-20	20-40	>40	
300 - 500	10.0	4.0	2.3	1.7	1.0	19.0
500 - 800	18.8	6.3	3.2	3.5	2.4	34.2
800 - 1200	20.6	6.5	1.6	1.4	1.7	31.8
1200 - 1500	8.0	2.1	0.6	0.2	0.1	11.0
< 1500	3.1	0.8	0.1	0.0	0.0	4.0
Total	60.5	19.7	7.8	6.8	5.2	100

Around 7300 ha of this elevation zone face high and very high erosion, while around 3830 ha of elevation zone between 800 and 1200 m faces the same two categories of erosion.

Elevation zone between 500 and 900 m is characterized by very high anthropogenic pressure due to the fact that most of the mountainous villages are located in this range of elevation. Therefore, the land use in this elevation zone mostly determines erosion rates. Each change of land use in this zone affects the environment and erosion process. The situation in this zone is less dramatic than in the past, even though the highest erosion rates are found in this zone in our study. Migration of rural population to urban areas and rapid decrease of number of inhabitants in this area mitigate erosion processes (Mustafić, 2008). Very big agricultural pressure on land is now decreased due to abandonment of villages. Sometimes large cultivated parcels are nowadays covered by grasslands and the Black Locust, which naturalize the habitat. A part of the study area is characterized by summer fires, especially in the Old Mountain. This indicates the vulnerability of ecosystem which could increase in the future due to climate change.

As a whole, the results obtained in this work approve the validity of the presented approach when compared with the soil erosion map and with other, more detailed, studies in the municipality.

5. CONCLUSIONS

The overall result of this work presented the soil erosion rate in Pirot municipality on a grid cell basis. This study confirms the results of the previous investigations and indicates the feasibility to apply GIS technology and USLE model to estimate quantitatively and spatially soil erosion loss at the 1235 km^2 area. Moreover, the results obtained in this study could be a valuable reference standpoint for managing and planning land use conservation in Pirot municipality. The obtained results classified the erosive process in the municipality of Pirot into low erosion category. Average annual soil erosion rate obtained in the study is 8.65 t ha^{-1} year^{-1}. More than 80% of the municipality is under insignificant or low erosion category. About 12% of the municipality was found to be under very high and high soil erosion category, higher than 20 t ha^{-1} year^{-1}. It means that the area of 148km^2, or 14800 ha, is under high and very high erosion risk. The study found out that there is a vertical distribution of erosion categories, indicating the highest erosion rates in the elevation zones between 500 and 800 m and 800 to 1200 m, respectively. A study found that proper land use management could even diminish the rates of soil erosion in these elevation zones.

Average values of soil erosion obtained through GIS on a grid cell basis are a base for the detection of the vulnerable zones in the study area, and a guide to future conservation measures. GIS offer systematic methodology in erosion factor determination, which is more facilitated by use of geostatistics, remote sensing, DEM and other tools and its use is necessary for any future conservation measures from the point of view of precision and adaptation, and time saving. Pirot municipality is quite large and it is characterized with high spatial heterogeneity of erosion factors. In this situation, the application of USLE model together with GIS is of substantial importance because it permits not only a fast evaluation of the actual situation but also the comparison of different mitigation measures and management scenarios under future land use and expected climate change.

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