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Evaluation soil erosion risk in mountain catchment by two empirical models

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Abstract. Productive capacity of soils is seriously affected by erosion, causing significant environmental damages. Soil erosion led to instability in ecosystems and decline in agriculture productivity as well as in forest territories. The negative anticipation about climate hesitation for acceleration soil erosion shows the need for monitoring the condition of the soils and taking adequate measures to reduce the risk. For that reason, different models for assessing soil erosion risk and determining potential levels of erosion are strongly advocated in researches. Two of the well-known and commonly used empirical models for the territory of Balkans are Erosion Potential Method (EPM) and Universal Soil Loss Equation (USLE). The objective of the research is to apply EPM and USLE models at the Sedelska River watershed, tributary of Struma River (Southwest Bulgaria), to assess soil erosion risk and investigate its spatial distribution. The results of the two methods are compared, finding that the EPM method slightly underestimates the final results compared to the USLE methodology. In both models, the territories with the strongest erosion risk were determined, and some of them coincide. When applying the USLE, it was found that the largest area of the research site is occupied by the lands on which a low actual risk is observed (47.10%). From the results obtained when applying the EPM, the watershed falls into the third degree of the Gavrilovich scale - a watershed with moderate erosion. The average amount of soil eroded assess with EPM is 3 t/ha/y. According to USLE the average potential risk with amounts of eroded soil of 100-200 t/ha y.

Key words: soil erosion, risk assessment, Sedelska river, EPM, USLE.

Introduction

Soil erosion is a global environmental problem that has significantly increased in scope and intensity in recent years. It is a constant process with significant monetary losses, causing destruction of the infrastructure, settlements and industrial objects, and damage on arable lands and forest territories. Soil erosion affect significant part of arable lands and led to losses in agricultural productivity (Borrelli et al., 2020), but mountain regions with steep slopes are also among highly vulnerable to soil erosion (Leh et al., 2013; Stanchi et al., 2015).

One of the most affected areas in Bulgaria is the watershed of the Struma River (Marinov & Bardarov, 2005, Blinkov et al., 2013), part of which is the Sedelska River. It is situated on the territory of State Forestry "Strumyani", which was established in 1968, with the main direction of its activity – erosion control. In the region the soils are highly susceptible of erosion and the slopes are predominantly steep and are a major source of sediment.

The purpose of the investigation is to evaluate soil erosion risk in the Sedelska River watershed by applying two empirical models - Universal Soil Loss Equation (USLE) and Erosion Potential Method (EPM).

Materials and Methods

The object of investigation is soil erosion risk at the watershed of the Sedelska river (Fig.1). Sedelska river is the right tributary of Struma River with 50.2 km^2 catchment area (Pavlova-Traykova, 2022a). In the past, the catchment area was affected by intensive animal husbandry, which caused enormous damage to the vegetation through grazing and with the release of new grazing areas, due to which the steep slopes have been left bare of grass and shrub vegetation. Also, again due to animal husbandry in the area, it was practicing the so-called branch-cutting farming. It is expressed in cutting a large part of the branches of trees to use them as leaf fodder in the winter, which also influences the degradation processes, through the reduced interception.

Everything said so far has led to highly eroded territories and need of application of erosion-controlled activities, which to some extents have controlled the processes in the watershed (Pavlova-Traykova, 2022a).

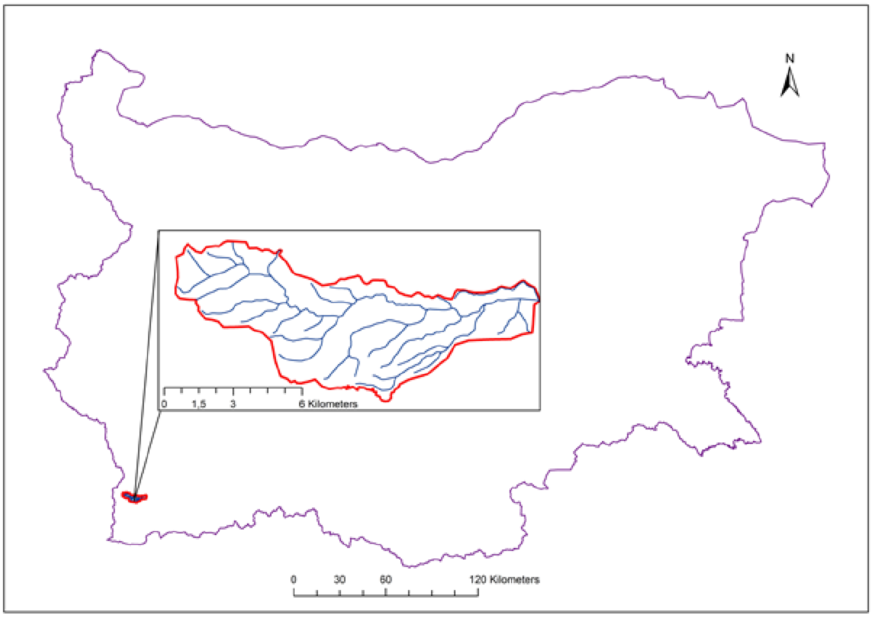

Fig. 1. Location of Sedelska river watershed

Two well-known empirical models were applied – USLE and EPM in the present research as follows:

Universal Soil Loss Equation (USLE)

This model was developed in the USA for erosion control design purposes (Wischmeier & Smith, 1965, 1978) and is known as the Universal Soil Loss Equation (USLE), adapted for Bulgarian conditions (Ruseva, 2002). The USLE uses six empirically-derived factors:

$$\boldsymbol{A = R \times K \times LS \times C \times P},$$

where: A – estimated average annual soil losses, t/ha; R – rain erosivity index, MJ mm/ha h; K – index for susceptibility to soil erosion, t ha h/MJ ha mm; LS – topographic index; C – index for the soil protection effect of the vegetation; P – index for soil protection effect of applied erosion control measures.

For calculation the rain erosivity index, a standard meteorological information is used, an adaptation was made for the conditions of Bulgaria (Ruseva, 2002) of the degree model of Richardson et al. (1983):

$$\boldsymbol{EI30 = \alpha(n \times P) \times 1.81},$$

where: n – the average annual number of erosive rains in a given location; P – the average annual amount of separate erosive rain in the same location; α – power model parameter to estimate the site-specific rainfall erosivity index.

The values of the soil erosion susceptibility index (K, t ha h/ha MJ mm) are calculated using the nomogram of Wischmeier et al. (1971), represented analytically by the formula:

$$\boldsymbol{K} = \mathbf{2.77} \times \mathbf{10^{-7}} \times \boldsymbol{M} \times \mathbf{1.14}(\mathbf{12} - \boldsymbol{a}) + \mathbf{0.0043}(\boldsymbol{b} - \mathbf{2}) + \mathbf{0.0033}(\mathbf{4} - \boldsymbol{c})$$

where: M = [%(0.1 – 0.002)] × [100 – % (<0.002)]; a – the percentage content of organic matter in soil; b – the aggregation code of the surface soil layer; c – the class of hydraulic conductivity of the soil profile.

The textural parameter (M) is calculated using the data on the soil texture and the content of organic matter in the surface soil horizons. The percentage participation of particles with a size smaller than 0.002 mm and from 0.1 to 0.002 mm, which are not available in the classification of Kachinski (1958) adopted in our country, is determined by the available fractions of mechanical elements under the assumption of linearity of the individual segments of the size distribution of soil particles on a semi-logarithmic scale.

The aggregation code (b) was determined based on the information on the structure of the surface soil layer in the morphological description of the folded profile (Ruseva, 2002).

The hydraulic conductivity class (c) was determined based on textural differentiation data and the textural class of the soil profile, defined as a weighted average of the mechanical composition of the soil-genetic horizons (Ruseva, 2002). The soil map in M 1:400,000 was used to estimate the index of susceptibility of the soil to erosion.

The topographic index (LS) combines the influence of slope and slope length on soil erosion losses. Topographic factor values were calculated using the formula of Moore et al. (1993). This formula has an advantage over the original formulas of Wischmeier & Smith (1978) because it uses the specific area from which runoff forms to evaluate the influence of slope length.

The potential risk of water erosion was calculated as the average annual value of the amount of eroded soil [t/ha y] in the absence of a vegetation cover.

The index for soil protection action of vegetation (C-factor) is defined as the average annual value of the part of soil losses from a given plant species and those from soil without vegetation. Estimates of the soil protective effect of vegetation are based on the distribution of lands according to permanent cover obtained as a result of the implementation of the CORINE project (2018). The values of the index for soil protection action of the vegetation (C-factor) of the used trench crop (maize) and crops with a fused surface (wheat and alfalfa) were calculated by agro-ecological regions based on the deterministic approach developed by Ruseva (2002).

The actual risk of water erosion was calculated as the average annual value of the amount of eroded soil [t/ha y] with vegetation cover determined according to the permanent cover map. Erosion risk was assessed as a product of the factors of rain erosivity, susceptibility to soil erosion, topography and the soil protective effect of vegetation.

Erosion Potential Model (EPM)

The EPM method or also known as the Gavrilovic method (Gavrilovic, 1988) is developped for application in torrential watersheds in southern and southeastern Yugoslavia (present-day Serbia), but it has been widely implemented in other countries (Margiorou et al., 2022; Milanesi et al., 2014; Pavlova-Traykova, 2021) and has provided reliable results for evaluating soil erosion. The EPM method takes into consideration factors based on surface geology and soil properties and also some descriptive parameters. According Gavrilovich, erosion is determined in 5 degrees (Table 1), but for Bulgaria it was considered that “low” and “very low” intensity of erosion to be combined and to be used - “low” erosion (Marinov & Gruev, 2002).

Table 1. Intensity of soil erosion

Intensity of soil erosion	**Z**
Very low	<0.19
Low	0.20-0.40
Moderate	0.41-0.70
High	0.71-1.0
Very high	>1.0

The annual volume of soil erosion accordng to the Gavrilovich method is determined by the following equation:

$$W_{year} = T \times H \times \pi \times \sqrt{Z^3}$$

where: W is the annual volume of soil erosion ($m^3/km^2/year$); H is the annual rainfall (mm); Z is erosion intensity; T is the coefficient of temperature, which is calculated as shown in the following equation:

$$T = \sqrt{\left(\frac{t'}{10}\right) + 0.1}$$

where: t is the mean annual temperature (°C).

The data used to calculate the temperature coefficient of the area and the amount of precipitation are from the Dupnitsa climate station and are for a 39-year period. Climate data are taken from the project Mitigating Vulnerability of Water Resources under Climate Change (2012-2014).

The erosion coefficient (Z) depends on four factors and is calculated as follows:

$$Z = Y \times X_a \times (\varphi + \sqrt{Isr})$$

where: *Y* is the soil erodibility coefficient; *Xa* is the soil protection coefficient; φ is the erosion coefficient; *Isr* is the average slope of the territories (%). These coefficients are determined by the tables which are presented in detail in other research (Pavlova-Traykova, 2021).

Afterthat, the results from this model are converted from $m^3/km^2/year$ to t/ha/year by applying the density equation (Zahnoun et al., 2019):

$$P = \frac{m}{v}.$$

Results and Discussion

USLE implementation

There are two types of precipitation in the catchment area at about 86% of the territory have an erosivity of 400 to 600 MJ mm/ha h y. The rest of the catchment (14%) has a rain erosivity of 800 to 1000 MJ mm/ha h y.

On the territory of the Sedelska river basin, four main soil differences have been established - Leached cinnamon forest soils, Leached cinnamon forest soils, heavy sandy-clay, Brown Forest soils and Alluvial and alluvial-meadow, sandy and sandy-clay soils (JICA, 2008). Cinnamon forest soils are the most common soil type in Bulgaria – covering 21.7% from its area (Marinov et al., 2005) and in the watershed of Sedelska River their variety is also the most widespread. According to distribution of soils, it was established that almost the entire territory of the watershed (99.57%) is characterized by medium to strong susceptibility to soil erosion and only 0.43% of the territory of the watershed is occupied by lands with medium susceptibility of soils to erosion.

According to the assessment of the topographic index (Moore et al., 1993) for the watershed of the Sedelska River, the largest share is land with a slope > 15° (62.77% of the entire territory), followed by the share of land with a slope of 9 to 12° (15.53%), the lands with a slope from 12 to 15° (9.60%) and the lands from 6 to 9° (8.82%). Lands with a slope from 0 to 3° occupy 2.14%, from 3 to 6° - 1.13%, of the territory of the Sedelska river basin (Table 2).

Table 2. Percentage distribution of the territory of Sedelska River catchment according to the slope degree groups (LS-factor).

Slope groups, degree	Share of the catchment's territory, %
0-3	2.14
3-6	1.13
6-9	8.82
9-12	1.53
12-15	9.60
>15	62.77

This distribution of the slope defines it as the main factor for the development of erosion processes in the observed territory. Such a conclusion was also made for the entire watershed of the Struma River (Martensson et al., 2001), part of which is Sedelska and for some other tributaries (Pavlova-Traykova et al., 2017; Pavlova-Traykova, 2019).

According to the potential risk of water erosion, assessed by the Universal Soil Loss Equation (USLE) the territory of the investigated Sedelska River catchment is divided into five classes. A high potential risk with amounts of eroded soil 100-200 t/ha y is spread over a significant share of the lands (68.77%) (Fig. 2). Moderate to high potential risk (40-100 t/ha y) is characteristic of 21.09% of the lands, followed by very high potential risk (7.39%) with an amount of eroded soil >200 t/ha y. The distribution of areas occupied by lands with low to moderate and moderate potential risk are respectively 2.14% and 0.62% relative to the catchment area.

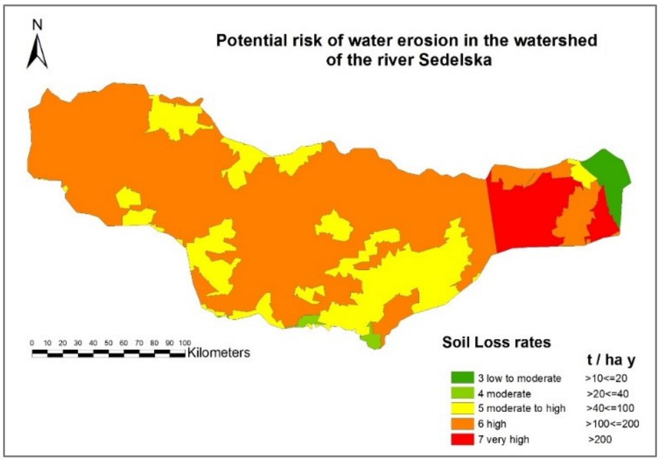

Fig. 2. Percentage distribution of the potential risk of planar water erosion for the territory of the Sedelska river basin.

The studied watershed of the Sedelska River falls into Petrichko-Sandanski and Ograzhdenski agro-ecological regions (V1; VI4). The results of the distribution of the territory of the Sedelska River watershed according to the method of permanent use were obtained when the boundaries of the watershed were determined with the updated map of CORINE 2018. According to the data obtained, mixed forests represented by 28.39%, followed by other agricultural lands (17.61%). With 16.21%, rare vegetation takes part, which occupies 891.03 ha of the catchment area, after which coniferous forests have the largest share with 14.38%. Grasslands occupy 13.64% of the area of the watershed, followed by broad-leaved forests with 6.80%. An insignificant share of the territory of the studied watershed is occupied by fields, urbanized lands and a complex of other agricultural lands, with 2.02% and 0.54%, respectively and 0.42 % of the total area.

According to the obtained results (Fig. 3), seven classes of actual risk of water erosion have been established on the territory of the Sedelska River basin. The largest area of the research site (2589.753 ha) is occupied by the lands on which a low actual risk is observed (47.10%), followed by lands with very low (20.28%) and high actual risk. The lands on which a very high actual risk is spread occupy 13.67% of the catchment area. Urbanized lands are represented by 0.93% and lands with a moderate actual risk of water erosion reveal at 0.71% of the entire catchment area.

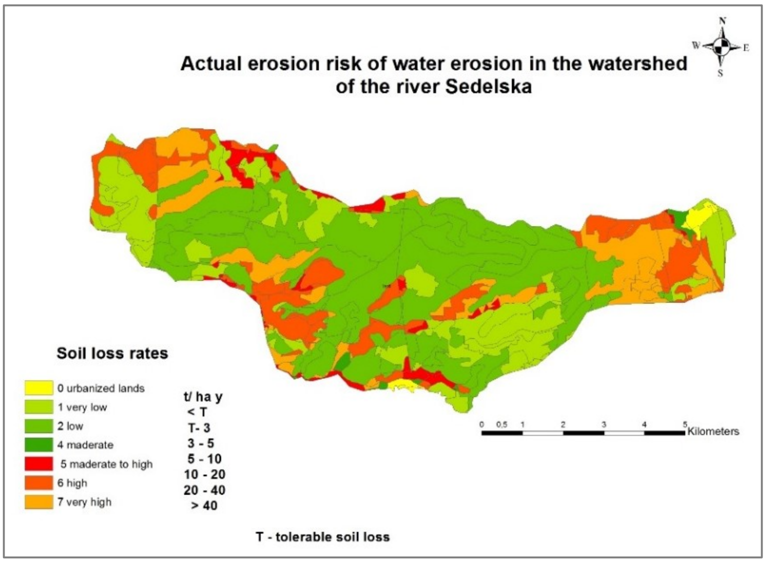

Fig. 3. Map of the distribution by classes of the actual risk of planar water erosion for the territory of the Sedelska river basin.

EPM implementation

Results for erosion coefficient Z is a measure of a region's vulnerability to erosion and in the watershed of Sedelska river shows significant presence of area in very high degree which are about 36% (Fig. 4). These are territories around the main tributaries of the river where coastal erosion is established like in other tributary of Struma (Pavlova-Traykova, 2022b) and in the part of the watershed, where are the steepest slopes. Similar results because of steep slopes and low vegetation cover are received for another watershed (Badaoui et al., 2023). The territories in low degree are about 50% and they covered forest areas and places where afforestation have been created.

Average value of Z is 0.49, which refers the territory of the watershed to a moderate erosion. There result shows significant part of the territories are with lower levels of erosion compared with the results for potential risk of erosion according to USLE. Lower level of potential erosion is also received by applying another model in this watershed (Pavlova-Traykova, 2022a).

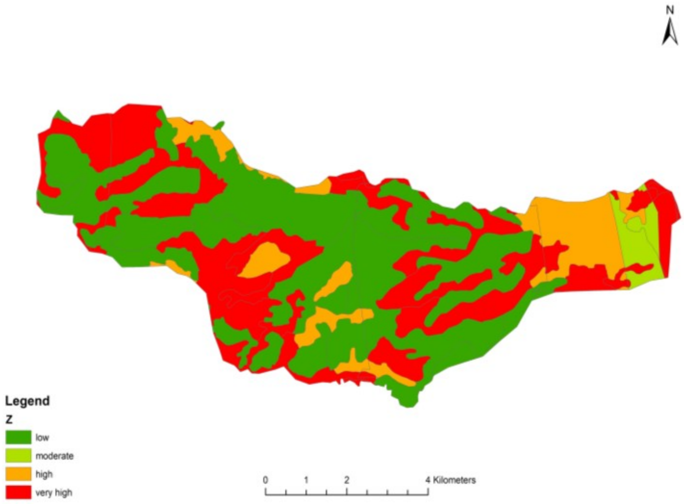

Fig. 4. Spatial distribution of erosion coefficient Z.

According to the estimation from soil samples, P (density equation) was calculated as 1.67, by this correction coefficient we transform the obtained results in t/ha/y to compare them with the results from USLE.

It was established that the results for annual soil loss varied a lot and with the most involving results are the territories bet-ween 5-10 t/ha/y (Fig. 5). One part of the territories assessed with very high intensity of soil erosion are also with high levels of W.

From the Fig. 5 it was well seen that the territories with higher soil loss are almost the same with these presented in Fig. 3. The average soil loss is 3 t/ha/y, and this result is lower compared to the USLE results.

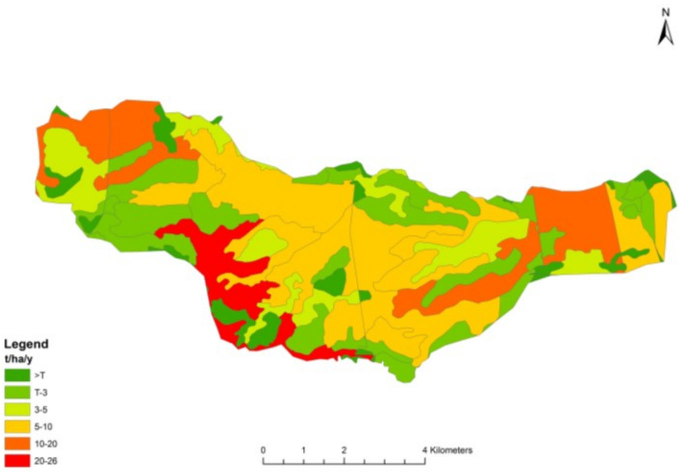

Fig. 5. Spatial distribution of volume of soil losses W.

Conclusions

The results of the two applied methods for soil erosion risk estimation (EPM and USLE) have been compared. In the both models, the territories with the strongest risk were determined, and some of them coincide. When applying the USLE, it was found that the largest area of the research site is occupied by the lands on which a low actual risk is observed (47.10%), followed by lands with very low (20.28%) and high actual risk (14.01%). From the results obtained when applying the EPM, the watershed falls into the third degree of the Gavrilovich scale - a watershed with moderate erosion. The average amount of soil eroded is 3 t/ha/y. It was established that the EPM method underestimates the final results compared to the USLE methodology, but some of the territories with high and very high risk of soil erosion are overlapped, which should direct the attention towards specific forestry practices in them.

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