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# ASSESSMENT OF SOIL EROSION USING FOURNIER INDEXES TO ESTIMATE RAINFALL EROSIVITY

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## Abstract

Soil erosion is one of the most extensive processes of land degradation around the world and its estimation is useful for spatial planning and policy makers for starting to remedy susceptible areas. For the moment, there is no single accepted calculation method, but most estimations are based on the classical or modified form of the Universal Soil Loss Equation (USLE). The goal of this study was to determine USLE's parameters, with accent on the main factor - the rainfall erosivity - using a modified Fournier index, and to estimate the potential erosion, in an area using GIS techniques. The rainfall aggressiveness was analyzed based on monthly and annual average values using the Fournier's index. Until now, this issue was not studied although it affects large areas. This study is based on an area located in the north-eastern part of Romania, in a catchment of 78.83 km$^2$, a river of 17.35 km and an elevation ranging from 137 to 720 m above sea level. A map of the annual soil erosion was developed for the study area showing small areas characterized by a very high soil loss hazard, with values between 150 and 500 t·ha$^{-1}$·yr$^{-1}$, indicating the necessity of intervention to limit the erosion.

*Key words:* erosion, rainfall, RUSLE, soil, USLE

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## 1. Introduction

Caused by natural or anthropic processes, soil erosion is one of the most common environmental problems around the world. Due to the high diversity of drivers and local conditions, the estimation of soil erosion hazard is still an activity that can be improved. The development of Geographic Information Systems (GIS) and meteorological databases have enabled the use of increasingly improved methods for estimating the risk of soil erosion at various scales (Demirci and Karaburun, 2012; Evans et al., 2018). Many methods and models are used at the moment for estimation of soil erosion, based on combinations of old maps, meteorological databases, mathematical algorithms and software applications (Beilicci et al., 2017; Duta et al., 2018; Stanga and Niacsu, 2016).

There are several methods used to estimate the soil erosion produced by rainfall but the most used ones, based on an empirical model, are the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and more recently, the revised versions of the equation (RUSLE) (Benavidez et al., 2018; Renard et al., 2011; Vieira et al., 2018). Both USLE and RUSLE equations have the same form, being the product of five terms, the difference between them being the way in which their terms are calculated.

One of the more important terms of USLE/RUSLE equation is the rainfall and runoff erosivity factor ($R$); it is statistically computed from the annual rainfall quantity and energy in every storm, correlated with raindrop size. It is the computation algorithm of this factor standing as one of the improvements of the RUSLE equation, being based on improved meteorological data and corrections applied for particular regions, such as regions characterized by long and intense rainstorms (Renard et al., 1991). The $R$ factor has a great spatial and temporal variation,

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usually being calculated as an average over a number of years using different equations, all of them based on meteorological data. This factor depends on rainfall amounts and intensities, which are not always available. However, the *R* factor must be adapted to a climatic region (Benavidez et al., 2018; Renard and Freimund, 2014).

If the calculation of *R* factor for large areas was improved during the years, for relatively small areas the calculation is still difficult due to the lack of meteorological data, mainly in the mountainous regions where the gauge stations are not so close each other.

In these cases, one of the most used equation for *R* calculation is given by the modified Fournier index (*F*) (Arnoldus, 1980), which uses the average monthly amount of precipitation for an important number of years, correlated with the altitude of the measurement point. The results showed a good agreement between the modified Fournier index and altitude (Horvath et al., 2016), but also the mathematical link between the *R* factor calculated using classic methods and the *F* factor (Hernando and Romana, 2015). Within a regional context, the subject was also shown to have good results by many other studies (Cartacuzencu et al., 2016; de Asis and Omasa, 2007; González-Morales et al., 2018; Panagos et al., 2014; Wang et al., 2018; Wolka et al., 2015).

The goal of this study was to obtain a reliable map of the soil erosion hazard for a relatively small area to be used as a decision instrument for the local administration; for this, the study uses the RUSLE equation and a modified Fournier index to estimate the rainfall and runoff erosivity factor based on GIS techniques.

## 2. Methodology

### 2.1. Study area

As a study area was chosen the Racaciuni Catchment, a hilly region affected by soil erosion, located in the north-eastern part of Romania, in the northern part of the administrative border of Bacau county (Fig. 1). The area of the basin is of 78.83 km$^2$ and the elevation of the study area ranges from 137 to 720 m above sea level. The average annual rainfall of the area is of 544 mm, while the area itself exhibits a wet climatic condition with a mean of the minimum and maximum daily temperatures of 4.6ºC and 20.6ºC, respectively. The soil erosion near the hydrographic network and its main tributaries is intensified by soil degradation as well as by the agricultural management practices (Cartacuzencu et al., 2016).

Details on the topography of the study area are presented in Fig. 2, representing the digital elevation model, the basis of the calculation for many of the erosion parameters.

The soil in the area is classified as loam, clay loam, sandy clay loam, and silty clay loam (Ovejanu et al., 2019). Sandy clay loam, silt loam and loam soils play a dominant role in soil erosion by water. The clayey soil in the north-eastern part of the area is the most susceptible to erosion.

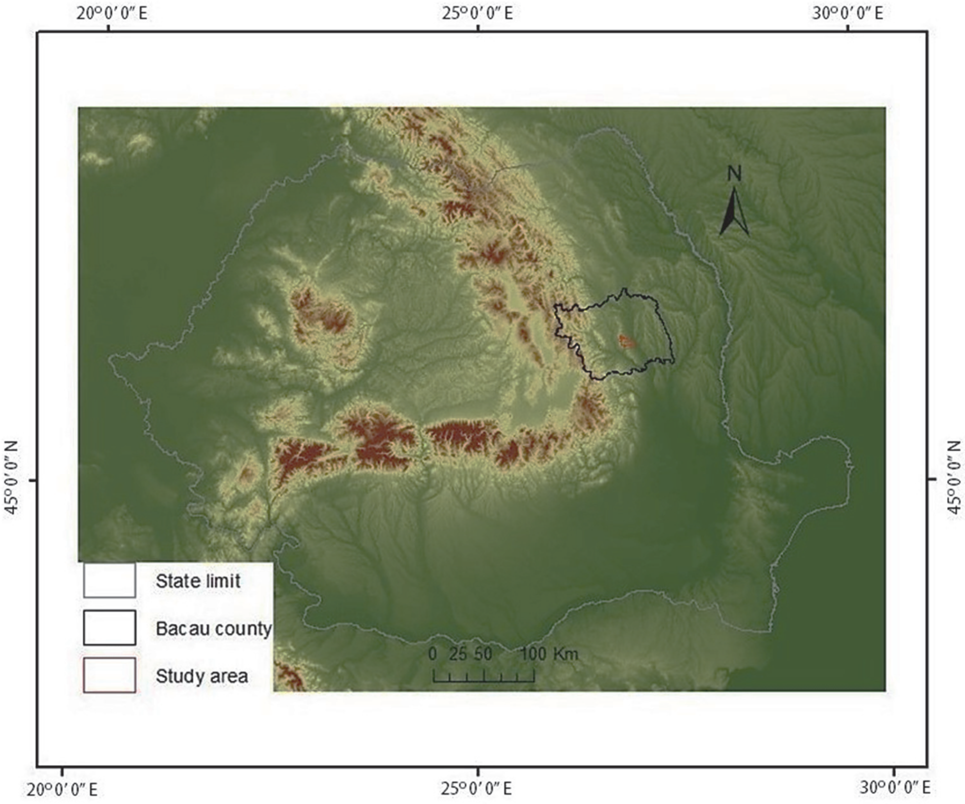


**Fig. 1.** The geographical position of the study area

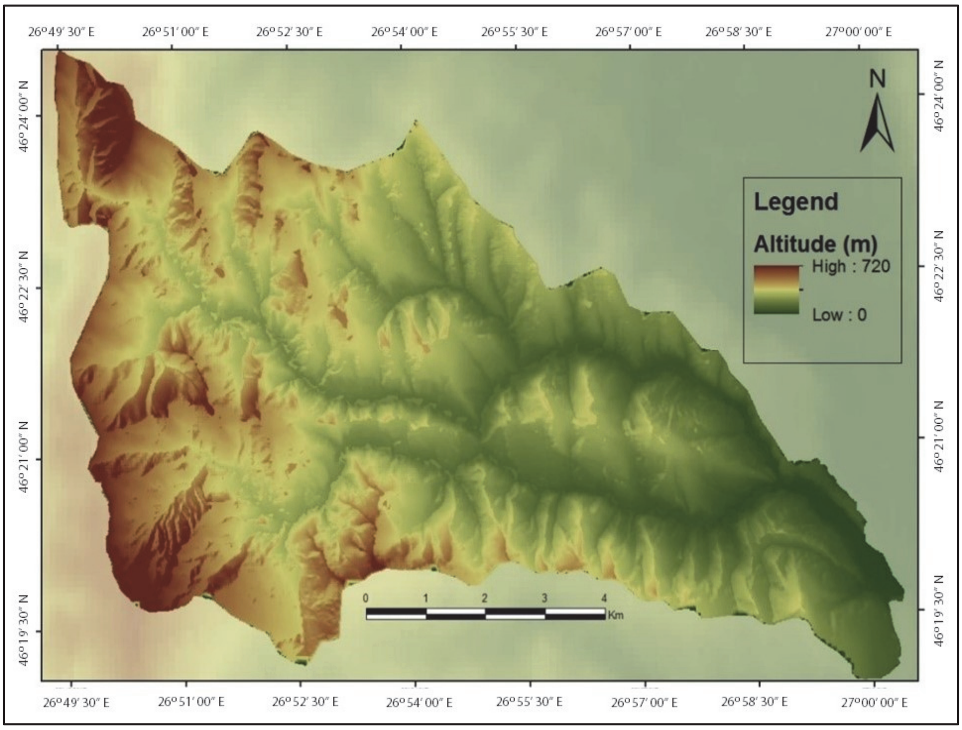


**Fig. 2.** Digital elevation model of the study area

### *2.2. Data sources and calculation methodology*

Digital Elevation Models (DEM) are excellent sources to calculate the most important topographic factors which can be associated with the flood phenomenon in a region. The DEM accuracy must be good enough to properly define flood-prone areas using a flooding model. In this study, the DEM has been obtained by digitizing contours at a 10 m-resolution on a 1:5000 topographic map using ArcGIS ® software. Based on DEM, a drainage data layer has been prepared with the flow direction for each filled DEM cell, one of the keys to obtain the hydrologic characteristics of a surface. The used ArcGIS ® function identifies the steepest direction of each pixel indicating the direction of water flow.

Computation of R factor for a given study area requires to calculate an average of rainfall data over as many years as possible. The rainfall data used for this study covers 45 years (1962 to 2007) and was provided by the Romanian Meteorological Department.

The general USLE/RUSLE equation presented in Eq. (1) was used to calculate the potential long-term average annual soil loss, i.e., the gross soil erosion (in $t\cdot ha^{-1}\cdot yr^{-1}$) A:

$$A = R \times K \times LS \times C \times P \tag{1}$$

The terms from the Eq. (1) were calculated as follows. The rainfall and runoff erosivity factor *R is usually* statistically calculated from the annual summation of rainfall energy in every storm, correlates with raindrop size and has a geographic variation. Because the detailed data is not available, the information was extracted from monthly rainfall. In these conditions, the *R* factor was calculated using Fournier index (Arnoldus, 1980), the index that takes into account the geographic condition, scale and monthly data. The *R* factor was derived from the rainfall data using Eq. (2) (Arnoldus, 1980):

$$MFI = \sum_{i=1}^{12} \frac{p_i^2}{p} \tag{2}$$

where: *MFI* is the modified Fournier index, $p_i$ is the average rainfall for the $i^{th}$ month (mm), and $p$ is the annual average rainfall. Arnoldus (1980) showed that the modified Fournier index is a good approximation of *R* to which it is linearly correlated.

Differentiated altitudinal positions of the stations allowed the correlation of the Fournier index with the altitude, based on the digital elevation model (Fig. 2), and the position in space allowed the analysis of spatial distribution of rainfall aggressiveness index. This precipitation variability led to an important variation over time of the value of the rainfall and runoff erosivity factor. The *R* factor was developed from the relationship between rainfall and elevation of the gauge stations Adjud - 103 m, Bacau - 184 m and Tg. Ocna - 243 m. In an approach similar to that used by Demirci and Karaburun (2012), the regression method proposed by Mezősi and Bata (2016) was used to estimate the value of the local erosivity, using ArcGIS ® software with Raster Calculator method.

The soil erodibility factor *K,* which is a measure of the susceptibility of soil particles to detachment and transport, depending on texture, structure, organic matter and permeability, was obtained from the soil map (Ovejanu et al., 2019).

The soil erosivity factor, *K*, relates to the rate at which different soils erode. Taking into account the texture of every soil type, classified with values from national studies, five classes of erodibility were established. The final result of the *K* factor calculation is given also by the soil texture (Panagos et al., 2015a).

The slope-length and slope-steepness factor, *LS,* was calculated using DEM model as a ratio of soil loss under given conditions to that at a standard site. The effect of the topography results from the combination of the two parameters, slopes length and slopes inclination degree, using the digital elevation model (Zhang et al., 2017).

The *LS* calculation from the original USLE is provided by the Eq. (3):

$$LS = \left(\frac{\lambda}{22.1}\right)^m (65.41\sin^2\theta + 4.56\sin\theta + 0.065 \tag{3}$$

where: $\lambda$ is the horizontally measured plot length, $\theta$ is the slope angle, and $m$ is a variable plot exponent adjustable to match terrain and soil variants. The $m$ factor varies between 0.5 (slopes of 5% or more) and 0.2 (slopes of < 1%).

In our work, for *LS* calculation Eq. (4) was used, proposed by Mitášová et al. (1996) as practical version of Eq. (3), because of the easiness of the implementation using ArcGIS ® software:

$$LS = \left(\frac{[\mathit{flowacc}] \times \mathit{resolution}}{22.1}\right)^{0.6} \times \left(\frac{\sin[\mathit{slope}] \times 0.01745}{0.09}\right)^{1.3} \tag{4}$$

where: flowacc = the flow accumulation, derived from DEM; slope = the slope in degrees, derived from DEM.

The cover management factor, *C,* is (dimensionless), was calculated from the Corine Land Cover dataset (2012) as a ratio relative to a standard situation. The *C* factor was determined from the Corine Land Cover dataset (2012), after reclassification, resulted in a number of five classes: built area (0), forest (0.1), pastures (0.20), vineyards (0.30) and arable land (0.4). All factors have been measured and integrated into a geographic information system.

The support practice factor, *P,* represents the ratio of the soil loss by a support practice to that of straight-row farming up and down the slope and was also calculated relative to a given situation (Renard et al., 2011; Stone and Hilborn, 2015) and usually is not calculated at sub-continental scale because is difficult to be calculated for small areas (Panagos et al., 2015b). For this project, the ratio was kept at 1, for the entire area, close to the value of 0.97 proposed Panagos et al. (2015b).

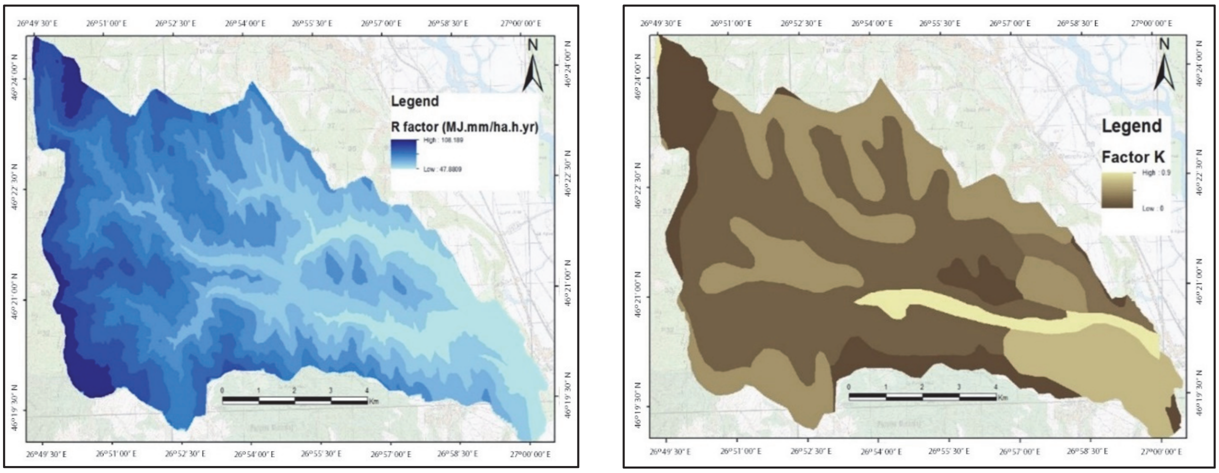
The entire database was converted to a raster format, using the Raster Calculator function from the Spatial Analyst extension, the value of potential soil erosion being computed for every pixel.

The R/USLE equation, supposing the multiplication of the five involved factors, was calculated using Raster calculator tool from ArcGIS 10.2 software at the level of each grid cell with 10 m spatial resolution.

## 3. Results and discussion

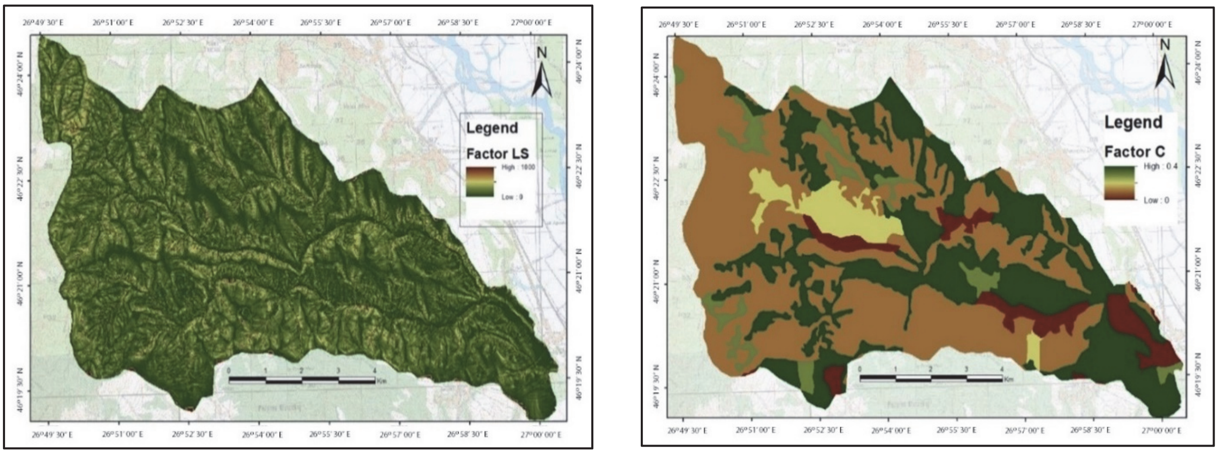
The results of the calculation for *R, K, LS* and *C* factors, using ArcGIS and the methodology presented above are presented in Fig. 3.

After the combination of all five factors (four calculated and one fixed), the soil loss in t/ha/year was obtained (Fig. 4). The rainfall erosivity factor map (Fig. 3a) showed values ranging from 47 to 108 $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot yr^{-1}$. Hence, the value for the annual soil erosion in the Racaciuni basin lies between 0 and 50 $t \cdot ha^{-1} \cdot yr^{-1}$ in the most investigated area (71% of the investigated area), but higher values can be observed in small areas (more than 300 $t \cdot ha^{-1} \cdot yr^{-1}$ on 2,8% of the investigated area).



(a)

(b)



(c)

(d)

**Fig. 3.** The calculated maps of the *R* factor (a), *K* factor (b), *LS* factor (c), and *C* factor (d)

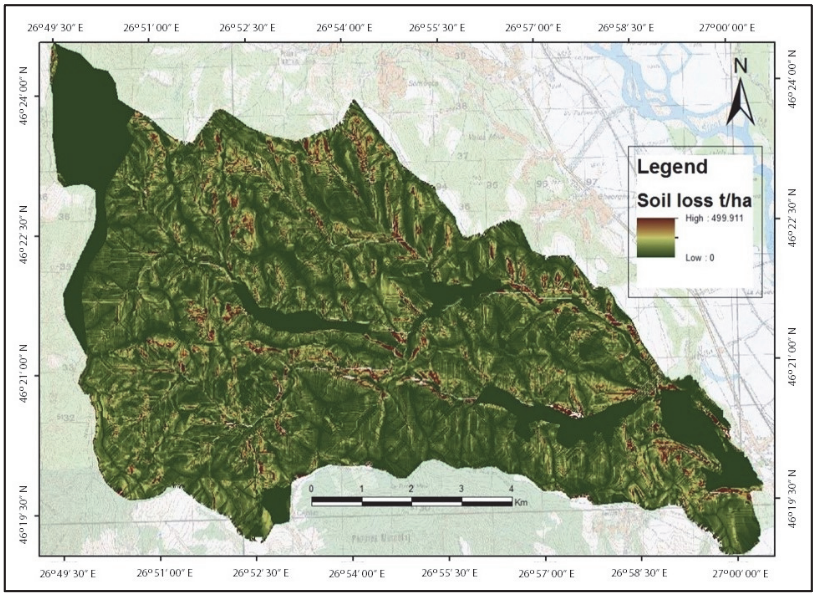


**Fig. 4.** The calculated annual soil erosion map

Dividing the obtained results for the soil loss in three classes based on the estimated erosion intensity one analysis of the global situation for the study area can be done. The analysis of all obtained maps showed that the lower erosion values have a significant predominance (36.6 %) in areas with a high degree of forestation, resistance to high erosion and a lower degree of anthropic influence. High erosion values areas are associated with zones characterized by high slopes and deforested piedmont areas in the neighbourhood of settlements. The estimated surfaces affected by high erosion represents 22.3 % of the catchment and 41.1 % of the surface presents a medium erosivity factor.

The obtained results were also compared to the results published by Panagos et al. (2012) for all EU countries. Fig. 5 presents the results o for the study area, selected from the larger map published by Panagos et al. (2012).

The first observation is the very important difference between the two maps, in terms of resolution. Comparing the two maps is now clear why was necessary to construct a new map at a better resolution because the map from Fig. 5 cannot be used for a detailed analysis.

A second observation is the existence of some differences between the two maps, even if the details of the second are very difficult to be followed. The differences are normal because for this study some of the R/USLE equation parameters were calculated using different data and methods.

One subject of discussion is the accuracy of the obtained map. As Benavidez et al. (2018) concluded, R/USLE model have many limitations coming from the validation of the model outside of the USA, where it was developed, the quality and accuracy of the input data, the influence of other types of erosion, etc.

In the case of our study, a part of these factors, the uncertainties associated with the proposed soil erosion model stem from particularities of the relief and the lack of data on measurements on the field for model validation.

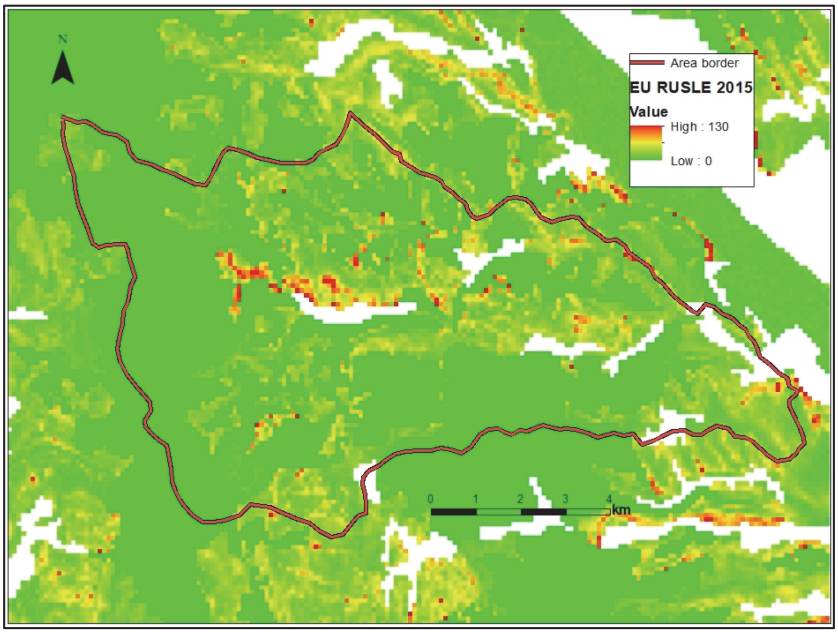


**Fig. 5.** The map of the study area from the soil erosion by water map (RUSLE2015) published by the European Union (adapted from (Panagos et al., 2012))

At the local administration level is necessary now to develop and implement an action plan to minimize the risk of erosion in the most exposed areas.

## 4. Conclusions

The objective of this study was to investigate the potential soil erosion hazard of catchment Răcăciuni using R/USLE equation and estimating the necessary parameters at the local scale.

The study estimated the soil loos, in a catchment with landslide problems. The study assesses the erosion using USLE and Fournier Index, modelled with a GIS function. Thematic layers of R/USLE factors (R, K. LS, C and P) were used to generate spatially distributed soil erosion rates.

The obtained values for the estimated annual soil erosion in the investigated area lies between 0 and 50 $t \cdot ha^{-1} \cdot yr^{-1}$ on almost three quarters of the surface (71% of the investigated area), Only 2,8% of the surface is potentially affected by very high erosion risk and upcoming studies must validate the hazard and propose the best solutions to avoid the risk. The obtained result was qualitatively compared with the existing results for the same area but at a much lower resolution.

The resulted map can be a support for making a decision and may help guide managers in selecting priorities to be addressed in anti-erosion management areas with the purpose to preserve human lives and infrastructure.

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