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THE QUANTITATIVE ESTIMATION OF THE SOIL EROSION USING USLE TYPE ROMSEM MODEL. CASE-STUDY- THE CODRULUI RIDGE AND PIEDMONT (ROMANIA)

Corina ARGHIUŞ[1] & Viorel ARGHIUŞ[2]
[1]*Colegiul Naţional Pedagogic „Gh. Lazăr'' Cluj-Napoca, Al. V. Voevod nr. 55, e-mail: corinarghius@yahoo.com*
[2]*Universitatea Babeş-Bolyai Cluj-Napoca, M. Kogălniceanu nr. 1, e-mail: arghius.viorel@ubbcluj.ro*

Abstract: This paper proposes a quantitative estimate of the current annual rate of soil surface erosion in the Codrului Ridge and Piedmont (due to the pluvial denudation and sheet erosion) and a spatial representation of the results by implementing GIS techniques. The database used in the application of the ROMSEM model (Romanian Soil Erosion Model) was consisting of Digital Elevation Model (DEM) with a resolution of 10 m, for computing the topographic factor (LS), soil map (with information about the type, texture, structure and degree of soil erosion), land use map, based on Corine Land Cover 2000 and corrected according to ortophotos dating from 2005, with a 0.5 m resolution, and the rainfall erosivity index map in Romania. The estimation of the surface erosion in the Codrului and Piedmont Ridge was achieved in two stages: first was assessed the potential erosion (the peak value of the erosion in an area devoid of vegetation) based on the climatic, topographic and soil factors. The effective surface erosion map was obtained in the second stage of the mathematical modeling erosion, by integrating the effect of natural or crop vegetation. The thematic map obtained was aligned to the present Romanian legislation (order no. 223 of May 28, 2002); the superficial erosion intensity map includes five classes: insignificant erosion <3 t ha^{-1} yr^{-1}, low erosion: 3-10 t ha^{-1} yr^{-1}, moderate erosion: 10-20 t ha^{-1} yr^{-1}; high erosion: 20-40 t ha^{-1} yr^{-1}, very high erosion: >40 t ha^{-1} yr^{-1}. The results obtained indicate an average annual rate of erosion of 0.575 t ha^{-1} yr^{-1} and a quantity of material discharged by surface erosion of 55,561 tons per year. 97.46 % of the study area has tolerable values (<3 t ha^{-1} yr^{-1}), revealing the low degree of human intervention, a good vegetation cover and the domination of the slopes with low inclination, less susceptible to erosion.

Keywords: soil erosion; ROMSEM model; GIS, Codrului Piedmont, erosivity factor

1. INTRODUCTION

The purpose of the investigation of the laminar erosion processes in the Codrului Ridge and Piedmont was a quantitative estimation of the present rate of the surface erosion and a spatial representation of the results by implementing the GIS techniques. The soil-erosion modeling may be useful in the design of the erosion-control measures and the evaluation of land-use management practices (Szilassi et al., 2006, cited by Ceteri et al., 2009).

The factors which influence the laminar erosion processes are the landscape features (slope, length and shape of slope), the climatic conditions, the properties of the soil, the land cover and the specific of the human activities.

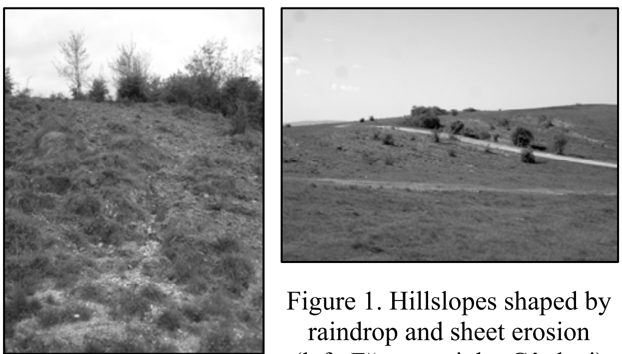

Figure 1. Hillslopes shaped by raindrop and sheet erosion (left, Fărcaşa; right, Gârdani)

Although the sheet erosion does not represent, directly, a factor of geomorphologic risk, the negative effects may be significant by removing the surface soil horizons, reducing the amount of vegetation cover (Fig. 1) that exposes the topsoil to the wind erosion etc.

2. THE STUDY AREA

The Codrului Ridge and Piedmont, located in north-western part of Romania (Fig. 2), represent geomorphologic units which are included in the morphogenetic aspects of the Western Hills. The study area combines features of the adjacent units: terraces and alluvial plains proper to the Western Plain, piedmont units- specific to the Banato-Crişene Hills, crystalline horsts and igneous intrusive bodies peculiar to the Apuseni Mountains.

The Codrului Ridge is a fault anticline that forms an arch, composed by metamorphic rocks, bordered by piedmont hills with a monoclinal structure, low inclination (3-10°) and homogeneous in terms of petrography (sedimentary rocks predominantly uncemented).

The sedimentary rocks occupy 91.4% of the total area, being present the sarmatian (in the south of the Homoroadelor Hills), panonnian and quaternary deposits (sand, gravel, clay and loessoid clay). Thus, in terms of lithology, the landforms shaped in the clay facies are dominated (landslides, mud flows, bad-lands) and that developed on silty sand deposits (gullies).

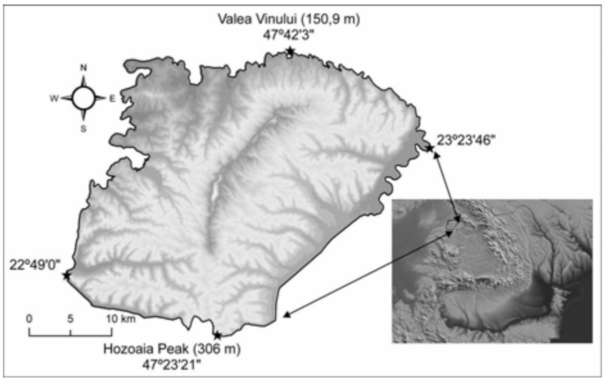

Figure 2. The location of the study area

The Codrului Ridge and Piedmont are some low relief units, recording an average altitude of 219.7 m and a low gradient, the area with slope less than 6 degrees owning a percentage of 71.25%.

The rainfall aggressiveness, determined accordingly to the modified Fournier Index (F_M) (Arnoldus, 1980), is low in the piedmont hills and moderate in the Codrului Ridge and the north-eastern extremity (>90). The forests occupy a high percent of the land use (37.45%), as a compact area in the Codrului Ridge and the Bortura-Someş interfluve area and as enclaves on almost all piedmont interfluves. Consequently, they provide a good protection against soil erosion. The luvisols class, represented by luvisols and albic luvisols is dominant, with over three quarters of the study area (86.73%). The soils with a fine texture (a clay and silty clay texture) hold the largest percentage in the Codrului Ridge and Piedmont (63.21%), making the soils highly prone to the surface erosion and triggering the gravitational processes. The anthropogenic pressure is low over the territory, the population density being less than national average- 47.09 inhabitants/km² (2002), compared to 90.94 inhabitants/km² (value derived from the National Census of the Population and Housing, 2002)

3. METHODOLOGY

Several mathematical models were developed to estimate the soil loss by surface erosion, as a result of the action of raindrops and sheet flow. One of the widely known and used model is USLE (Universal Soil Loss Equation Universal), developed by Wischmeier & Smith (1978). It estimates soil loss from a hillslope caused by raindrop impact and overland flow, taking into account factors such as rainfall erosivity, soil type, landscape characteristics, land use (including types of crops) and management practices of agriculture. The model was developed by applying statistical methods on data obtained through experimental measurements and indicates, with a good precision, the areas with potential gully processes. The equation for calculating the mean annual rate of soil erosion is the following:

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

A- the average annual soil loss (t $acre^{-1}$ yr^{-1});
R- the rainfall erosivity factor, evaluated as a product of the total storm kinetic energy (E) and the maximum 30-min intensity (I_{30});
K- the soil erodibility factor;
L- the slope length factor;
S- the slope gradient factor;
C- the vegetation and crop management factor;
P- the support practices factor.

A new version, RUSLE (Revised Universal Soil Loss Equation), was developed by Renard et al. (1997); it keeps the USLE form, being improved the methods for calculating the terms of the mathematical equation.

The USLE methodology was adapted to the Romanian soil and climatic conditions by the team of researchers of the Institute of Pedology and Agrochemical Researches in Bucharest. Thus, in 1979, Moţoc et al. have developed the ROMSEM model (Romanian Soil Erosion Model), using the experimental data obtained at the several research stations in the country (Perieni-Vaslui county, Aldeni-Buzău county, Bâlceşti-Argeş county, Valea

Călugărească-Prahova county and Câmpia Turzii-Cluj county). This model was reconfirmed in 2002 (Moțoc & Sevastel, 2002). The estimated annual soil loss is based on the following equation:

$$E = K \cdot S \cdot L^m \cdot i^n \cdot C \cdot C_s \quad (2) \text{ where,}$$

-E- the average annual rate of the surface erosion (t ha^{-1} yr^{-1});
-K- the rainfall erosivity factor, evaluated based on the rainfall aggressiveness, obtained as a result of $H \cdot I_{15}$ (H- the amount of precipitation fallen during the entire rain event, I_{15}- the intensity of the torrential nucleus lasting 15 minutes);
-S- the soil erodibility coefficient;
-L- the slope length factor; it is determined using a L^m function, where m=0.3 for the straight slopes, m=1.2 for the convex slopes and for the slopes with concave profile m=0, 6);
-i^n, where i represents the slope angle (%) and n=1.4;
-C- the cover management factor;
-CS- the correction coefficient for the effect of the erosion control measurements.

The factors of the soil erosion processes control are grouping in two categories:
→ the factors which trigger erosion: rainfall erosivity (Ap), topography (R) and soil (S);
→ the factors that control erosion: vegetation (C) and anti-erosion works (Cs).
The combined action of the Ap, R and S factors represents the potential erosion (Ep), while the action of all the factors represents the effective erosion (Eef).

Ep= Ap·R·S (3)

Eef= Ap·R·S·C·Cs (4) (Moțoc & Sevastel, 2002)

The quantification of surface erosion process in the Codrului Ridge and Piedmont was conducted according to the recommendations of the present Romanian legislation: order no. 223 of May 28, 2002, for approving the Soil and Agrochemical Studies Drawing Methodology, of the National and County Land System for Monitoring Soil-Land for Agriculture, published in the Official Gazette, Part I, no. 598 of August 13, 2002, Appendix. 4,- Content Standards, Chapter II, Article 8, "the risk indicators are established only for the surface erosion, the risk being calculated using the method recommended by Moțoc et al., 1978. The risk classes, in t ha^{-1} yr^{-1} (for the gully erosion and landslides there are not yet validated risk assessment models), are:
→ insignificant erosion: <3 t ha^{-1} yr^{-1};
→ low erosion: 3-10 t ha^{-1} yr^{-1};
→ moderate erosion: 10-20 t ha^{-1} yr^{-1};
→ high erosion: 20-40 t ha^{-1} yr^{-1};
→ very high erosion: >40 t ha^{-1} yr^{-1}''.

The recent methodology for applying the RUSLE or USLE models requires the use of the GIS techniques (Lu et al., 2004, Saavedra, 2005, Lastoria et al., 2008, Yuksel et al., 2008 etc.). The importance of the GIS techniques integration to quantify the surface erosion risk is determined by the speed of the performing operations, the accuracy of the results and the possibility of their spatial representation.

The database used for estimating the annual rate of surface erosion based on the ROMSEM model was consisting of the Digital Elevation Model (DEM), with 10 m resolution, the soil map (with information about the type, texture, structure and degree of soil erosion), the land use map, based on Corine Land Cover 2000 and corrected according to the 2005 ortophotos with a 0.5 m resolution, the rainfall erosivity index map in Romania (Moțoc & Sevastel, 2002) and information about the distribution of soil erosion control works (source: ANIF, 2009). The final product, the surface erosion map of the studied territory (Fig. 9), results by integrating and applying the GIS overlay technique of overlapping, combining and spatial analysis of the layers (Fig. 3).

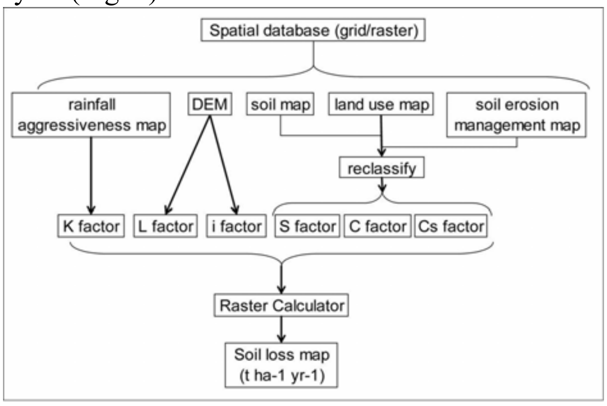

Figure 3. The flow chart showing the methodology for quantify the surface erosion using GIS techniques

The methodology for implementing the GIS techniques for the ROMSEM model, used to quantify the soil loss by Patriche et al., 2006, Anghel & Todică, 2008, Bilaşco et al., 2009 etc., is the following:
→ K represents the rainfall erosivity index; it was extracted from the pluvial aggressiveness map in Romania (Moțoc & Sevastel, 2002). According to it, The Codrului Ridge and Piedmont belong to the area no.10, which has a rainfall erosivity coefficient (Ka) of 0.080

The morphological aspects that influence the sheet erosion are the slope gradient, slope length and its shape. The longer the length slope, the greater the amount of cumulative runoff. Also, the steeper the hillslope, the higher the velocities of the runoff which contribute to erosion.

→ L represents the slope length factor; it is defined as the distance from the source of runoff to the point where the deposition begins, or runoff becomes focused into a defined channel (Simms et al., 2003).

The slope length was estimated using the L^m function, where m=0.3 for slopes' length less than 100 m and m=0.4 over this value. The GIS methodology involves the calculation of the slope length based on the 'upslope area'' (As). According to Patriche & Moțoc (2007), cited by Magyari-Sáska & Haidu (2008), the L factor for the Romanian conditions is derived from the following equation:

$$L = 1{,}4\left(\frac{A_s}{22{,}13}\right)^{0{,}3} \quad (5)$$ where

As- the value representing the flow accumulation.

This equation is based on the formula proposed by Moore et al. (1993) as:

$$L = 1{,}4\left(\frac{A_s}{22{,}13}\right)^{0{,}4} \quad (6)$$ (Moore et al., 1993)

The As factor, representing the number of cells contributing to flow in a given territory (Lastoria et al., 2008), was determined according to a 10 m resolution DEM (Digital Elevation Model), using the Spatial Analyst and ArcHydro Tools extensions of ArcGIS 9.2 software. The expression implemented in Raster Calculator is following:

1.4*Pow([flowacc]/22.13, 0.3) (7) where flowacc is the theme name used for flow accumulation grid file, resulting L factor map.

→ i factor, was estimated using the Moțoc & Sevastel methodology (2002), using a function that gave the best experimental results: i^n. Using the Raster Calculator tool was introduced equation above, resulting, thus, the slope factor map. The slope length factor and the slope gradient factor are typically combined together and defined as the topographic factor, LS (length-slope factor), named in Romanian literature Li (Fig. 4).

→ S- the coefficient of soil erodibility.

The soil erodibility was determined based on the Methodology to elaborate the pedologic studies' (ICPA, 1987); it established the erodibility classes according to the genetic type of the soil, degree of erosion and their texture. The first step has been the selection of the soil erodibility coefficients (as Moțoc & Sevastel, 2002), operation followed by the reclassification of the soils map in the erodibility indices identified. Using Spatial Analyst extension (Reclass tool) is obtained, thus, the spatial representation of the soils erodibility (Fig. 5).

The soil erodibility factor in the Codrului Ridge and Piedmont varies between 0.8 and 1, the average value being 0.909. The spatial variability is low, the homogeneity of the indices being demonstrated by the low value of the standard deviation (0.397). The soils most susceptible to erosion are the eroded types of the luvisols and the eutricambosols, characterized by a coefficient of erodibility with value 1.

→ C- a coefficient which expresses the influence of the type of the land use (crop and natural vegetation) on the erosion processes.

The land use map was obtained by delimiting the homogeneous parcels in conformity with the

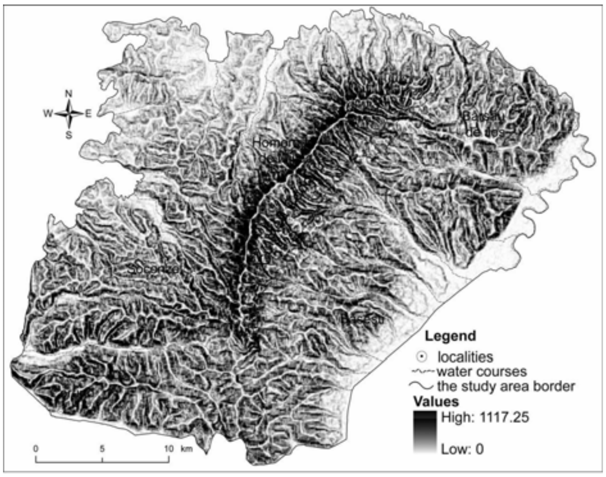

Figure 4. The Li factor map

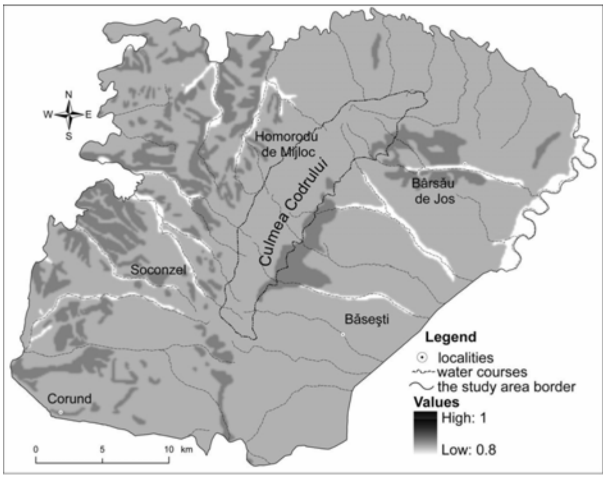

Figure 5. The soil erodibility index map

Corine Land Cover (2000) database and the ortophotos dating in 2005, with a 0.5 m resolution. The values of the coefficients specific to each type of land use were extracted from the Romanian database (Moțoc & Sevastel, 2002).

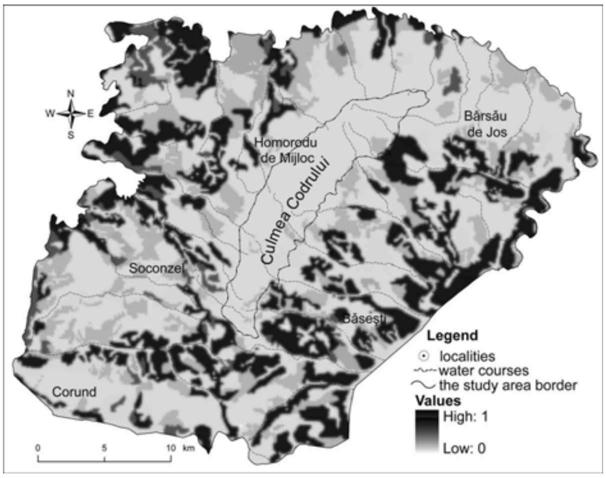

Figure 6. The C factor map

The mean value of the land susceptibility according to the C factor is quite low (0.298), due, in particular, to the high percentage of the forest areas (37.45%), with a very low susceptibility index (0.001); in addition, 6.6% of the territory is consisting in built and aquatic areas, with C value equal to 0. The highest values are specific to the arable land (coefficient 5), with a percent of 35.84% (Arghiuș, 2010). The land use map was reclassified as those erodibility indices, achieving, thus, the spatial distribution of the C coefficient (Fig. 6).

→ Cs- the corrected coefficient depending on the anti-erosion measures adopted (the supporting practices factor). The corresponding values of the various measures and methods for combating soil erosion were determined by Moțoc (Moțoc & Sevastel, 2002).

Although we have the information on the extent of the works undertaken in the region for combating the soil erosion processes, the lack of data about the nature/type of those, did not allow their integration into the equation. The Cs factor misses from the equation, which involves considering it as having the value of 1, which means that no protection measures have been taken. We believe, however, that its absence does not affect the results significantly, given the reduced percentage of anti-erosion works and that is a factor which has no influence on the potential erosion of a territory.

4. RESULTS AND DISCUTIONS

The estimation of the surface erosion in the Codrului Ridge and Piedmont was achieved in two stages. Firstly, the potential erosion was quantified, conditioned by the climatic factors, topography and soil; it represents the maximum amount of erosion that can affect an area devoid of vegetation (Fig. 8). Thus, the soil erodibility, rainfall erosivity and topography layers were overlapped by applying the Raster Calculator tool of the Spatial Analyst extension of ArcGIS 9.2 software, in order to calculate the potential soil erosion of the study area. The used formula is the following:

Potential soil erosion index= length-slope index · rainfall erosivity · soil erodibility or

Potential soil erosion map= LS factor map · K factor map · S factor map (8)

According to the calculus (Table 1), the mean annual value of the potential erosion in the study area is 1.105 t/ha/year, which corresponds to a very low erosion risk. The surfaces without erosion/with insignificant erosion (lower than 3 t ha^{-1} yr^{-1}) hold an overwhelming percent, 96.9%; in addition, 88.1% of the territory is characterized by potential erosion under 1 1 t ha^{-1} yr^{-1}. The areas with a moderate, high or very high susceptibility to the surface erosion have a low frequency, together holding a percentage of 0.18% of the total (Fig. 7); they overlap steep slopes, characterized by a lack of the protective cover and a soil cover composed by the eroded types of the luvisols.

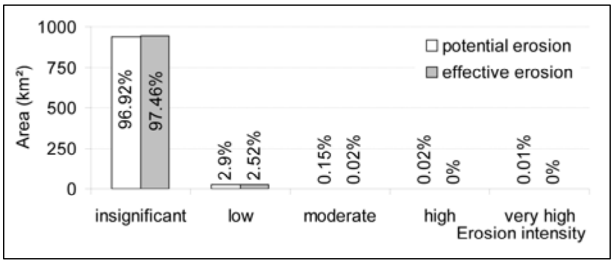

Figure 7. The histogram of the erosion intensity classes of the surface erosion

The last step of the mathematical modeling of the erosion due to the splash erosion and sheet flow was to integrate the effect of the spontaneous or crop vegetation, resulting in, thus, the effective erosion map (Fig. 9). The used formula is the following:

The effective soil erosion index= potential soil erosion index land cover management index or

The effective soil erosion map= potential soil erosion map C factor map (9)

Table 1. Database obtained from mathematical modeling of the surface erosion

The erodability classes (according to order no. 223 of May 28, 2002)		The potential erosion		The effective erosion	
		Area (km²)	Percent (%)	Area (km²)	Percent (%)
insignificant	<3 t ha^{-1} yr^{-1}	936.517	96.92	941.735	97.46
low	3.01-10 t ha^{-1} yr^{-1}	28.022	2.90	24.350	2.52
moderate	10.01-20 t ha^{-1} yr^{-1}	1.449	0.15	0.193	0.02
high	20.01-40 t ha^{-1} yr^{-1}	0.193	0.02	0	0
very high	>40 t ha^{-1} yr^{-1}	0.097	0.01	0	0

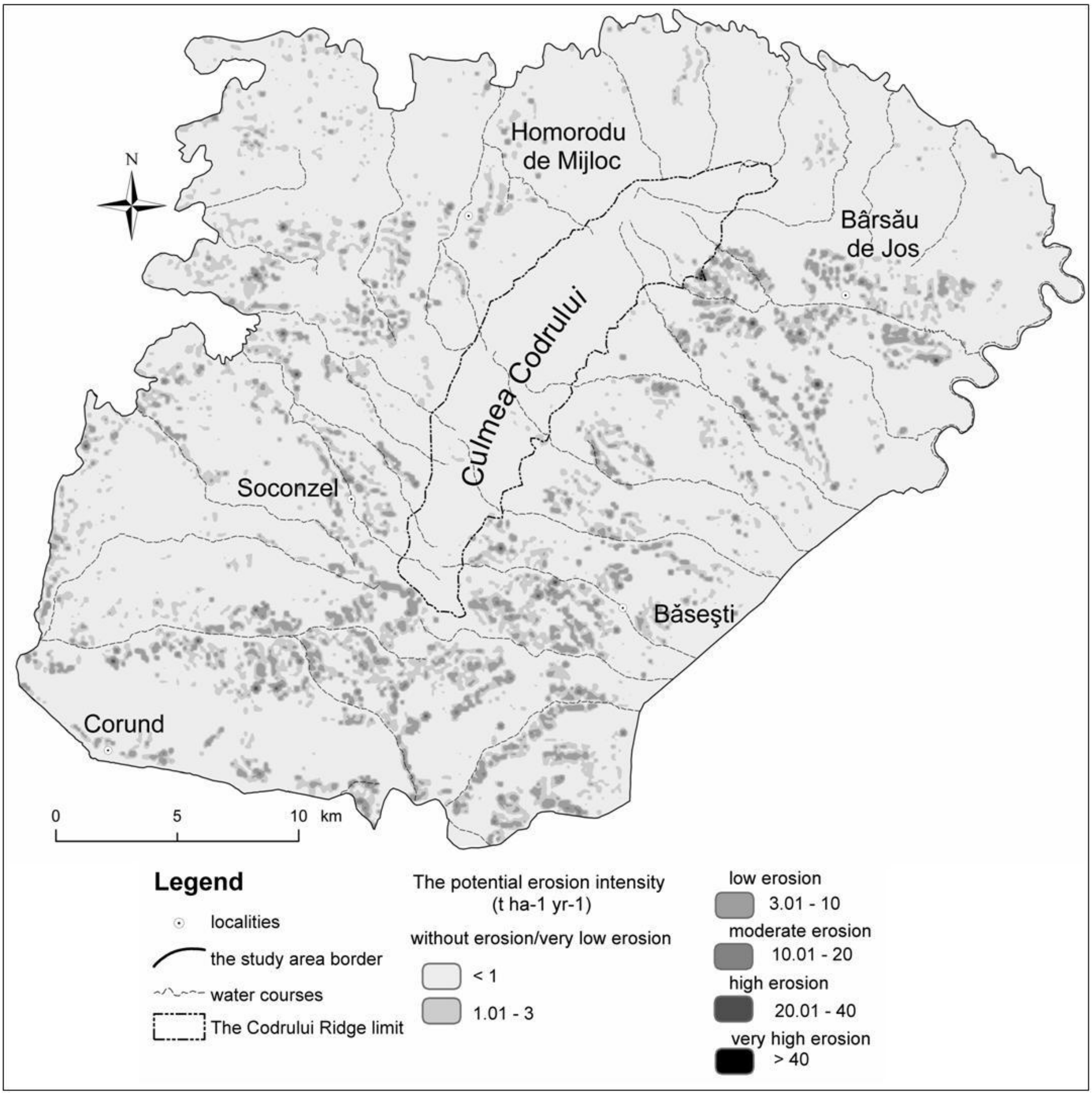

Figure 8. The potential erosion map

The results indicate an average annual rate of erosion of 0.575 t ha^{-1} yr^{-1}, the quantity of the material discharged through surface erosion being 55,561 t yr^{-1}. Comparing the mean values of the potential and effective erosion (Fig. 7) reveals that the land use' integration leads to a lower annual average rate of soil degradation by surface erosion with 192.1%. It proves that the soil is protected by vegetation, one third of the surface being covered by forests. The highest values, exceeding 10 t ha^{-1} yr^{-1}, represent 0.02% of the total, corresponding to the steep slopes, with sparse vegetation.

The analysis of the soil erosion map indicates that 97.46% of the territory presents tolerable values (<3 t ha^{-1} yr^{-1}). As a result of applying the ROMSEM model, did not results the areas with a high or very high susceptibility to the surface erosion (>20 t ha^{-1} yr^{-1}).

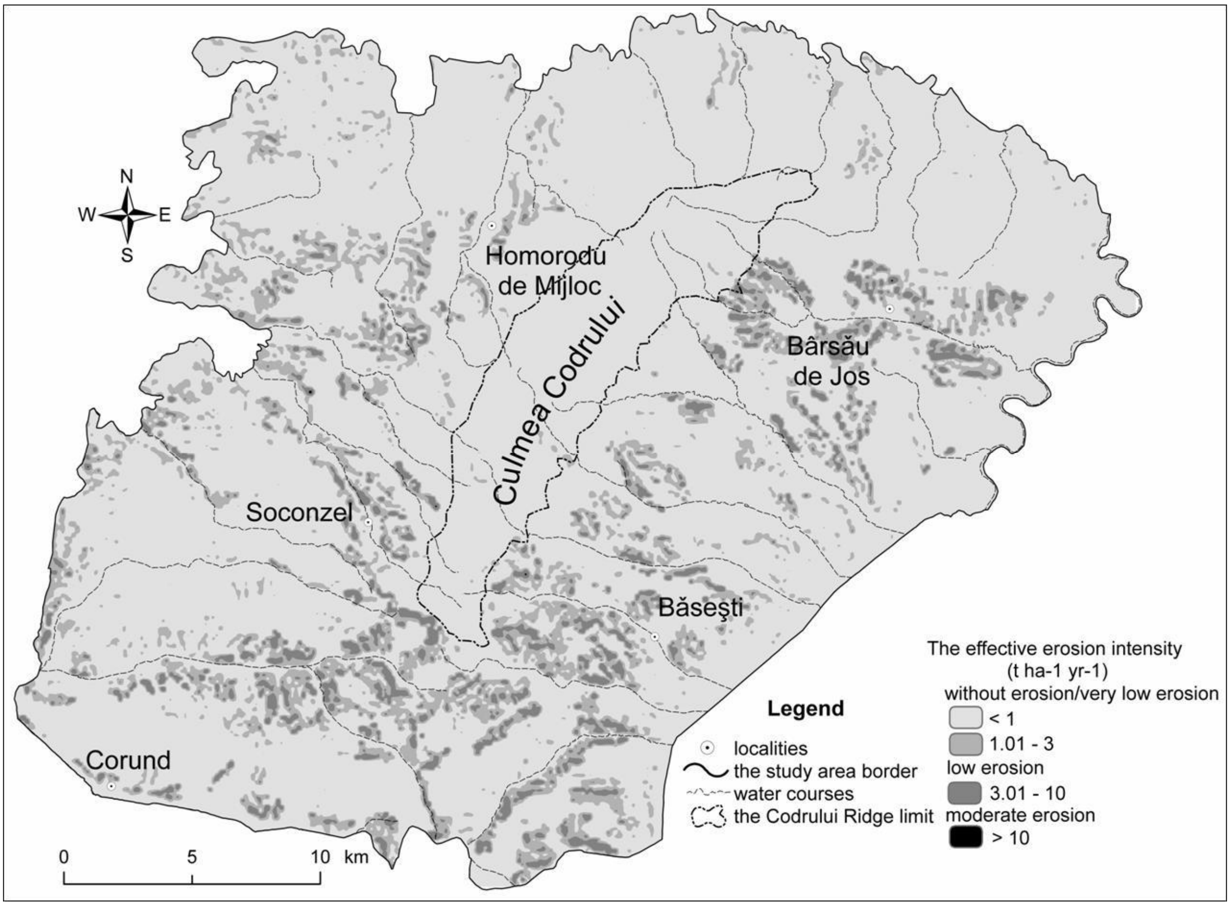

Figure 9.The effective erosion map

Table 2. The mean annual specific sediment yield and related parameters in Sălaj basin - Sălsig gauging station (1971-2004) (source of data: "Romanian Waters" National Administration, Someş-Tisa Branch)

Basin area (km²)	Area in region (km²)	Discharge ($m^3 s^{-1}$)	Suspended sediment discharge ($kg s^{-1}$)	Suspended sediment concentration ($g l^{-1}$)	Mean specific sediment yield obtained by measurements ($t ha^{-1} yr^{-1}$)	Mean specific sediment yield obtained by modeling ($t ha^{-1} yr^{-1}$)
454	281	2.15	1.04	0.487	0.725	0.672

The accuracy of the calculus was evaluated by comparing the results with those obtained by applying the same methodology in the other regions: in Romania (0.64 t ha^{-1} yr^{-1} in the Suceviţa basin, Anghel et al., 2008; 0-1.5 t ha^{-1} yr^{-1} for 98.5 % of the Someşean Plateau, Bilaşco et al., (2009), <1 t ha^{-1} yr^{-1} for 80.7% of the Măhăceni Tableland, Onac, 2009), Hungary (0.67 t ha^{-1} yr^{-1}, Hajdú-Bihar County and 1.02 t ha^{-1} yr^{-1}, Szabolcs-Szatmár-Bereg County, Podmanicky et al., 2009) or Europe (0-1 t ha^{-1} yr^{-1} for the studied area, Selvaradjou et al., 2000) allow us to consider valid the applied model.

In order cu obtain a realistic image about the soil loss, the GIS data were compared to the mean annual specific sediment yield (1971-2004 period), measured in Sălaj basin-Sălsig gauging station, situated in the southeast of the studied region. It is the single station in the region with suspended sediment discharge data records. The results show that the data obtained by modeling are very close to those obtained by measurements (Table 2).

5.CONCLUSIONS

The Codrului Ridge and Piedmont present a low erosion risk, due to the low level of human intervention, the good cover (forests, shrub vegetation) and the domination of the low angle slopes, less susceptible to the erosion.

The estimation of the annual amount of soil discharged through laminar erosion gives us the possibility to identify the susceptible potential areas and to intervene with anti-erosion measures such as terracing slopes to reduce their length and inclination, to reforest the areas for soil protection etc. The application of the used model can be improved by estimating the effects of the surface erosion process in time to predict, thus, the trends of the soil degradation and increasing the spatial resolution of the factors taken into account.

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