

ASPECTS REGARDING SOIL EROSION SPATIAL MODELING USING THE USLE / RUSLE WITHIN GIS

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ABSTRACT

The present study refers to soil surface erosion and applies the Universal Soil Loss Equation within GIS in order to test certain methods of quantification for the control factors, as the USLE / RUSLE imply. The models' testing implies the comparison of estimated values with the ones measured for 2 small hydrographic basins placed in the Curvature Sub-Carpathians, tributary to the Zăbala River. At the same time the scientific paper includes the application of USLE model for the sterile terrigenous masses situated in the former sulphur quarry up in the volcanic Mountains of Calimani.

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1. INTRODUCTION

The scientific approach regarding the problematic of soil erosion began in the thirties at the initiative of the American specialists in the field of pedology and agronomy. The research focused on the identification and quantification of the erosional processes control factors, resulting in the elaboration of the universal erosion equation (USLE) (*Wischmeier W. H., Smith D. D., 1978*). The great majority of subsequent studies dealt with the calibration of the parameters intervening in this equation, in order to quantify real erosion and reproduce trusty measurements for concrete terrain parcels, characterized by particular combinations of the physical-geographic and human induced elements. Consequently, in Romania, such calibrations were carried out by *Moșoc M. et al. (1975)*, resulting in one equation to be considered proper for the specific conditions of the Romanian territory, equation implemented by the *ICPA (1987)* in the methodology used for the elaboration of pedologic studies.

Beside these calibrations, the researchers' effort concentrated also on the revising of the universal erosion equation. In this respect, *Williams J. R. (1975)*, proposes a modified equation (MUSLE) for the quantification of the alluvium resulting from erosion following each rain, and a collective of American researchers (*Renard R. G., Foster G. R., Weesies G. A., Porter J. P., 1991*) proposes a revised, computerized and more complex equation (RUSLE).

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2. POSSIBLE QUANTIFICATIONS OF THE USLE / RUSLE FACTORS.

The present study regards the soil surface spatial modelling through the application of the universal soil loss equation inside the GIS in order to test different quantification methods of the control factors, according to the USLE (*Wischmeier & Smith, 1978*), adapted by *Moşoc et al., 1975*), or RUSLE (*Renard et al., 1997*).

The models testing was accomplished through estimative values comparison with the ones measured (*Gaspar, Cristescu, 1987*) in the perimeter designated by the two small hydrographic basins (tributary to the Zăbala River) situated in the Curvature Sub-Carpathians. The input parameters are represented by the digital elevation model, generated at a resolution of 10m (*Capătănă V.*, PhD student, „Al. I. Cuza” Univ. of Iaşi), the soil map at 1:200.000, the land use according to CORINE land cover 2000 and the 3 (red) and 4 (infrared) spectral bands of the LANDSAT image from 18.06.2003. The spatial information was computed with the TNT mips 6.4 software.

Regarding the equation adopted by *Moşoc et al. (1975)* for the pedo-climatic conditions characterizing the Romanian territory, the factors intervening in the USLE (R, K, LS) differ substantially, as far as the their conception and quantification are concerned, compared with the corresponding factors to be found in other USLE / RUSLE equations applied at the international level. Consequently, these factors cannot be used in combination.

USLE and RUSLE have the same mathematical expression:

$$E = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

where:

- E: is the average annual erosion rate (t/ha an);
- R: is the rainfall erosivity;
- K: is the soil erodibility;
- L: is the slope length influence;
- S: is the slope steepness influence;
- C: is the correction coefficient for the effect of vegetation;
- P: is the correction coefficient for the effect of erosion control measurements.

The difference resides in the factors' quantification manner. For instance, in RUSLE, the evaluation of rainfall erosivity factor was revised in order to account for the precipitations falling on cvasi-horizontal surfaces, the calculating algorithm used for LS factor was changed, a time dimension was added to the erodibility factor etc.

Rainfall erosivity (R)

Rainfall erosivity (R) represents the annual sum of the products between the energy of the erosive rainfalls (E) and their maximum 30 minutes intensities (I_{30}):

$$e = 0.29 [1 - 0.72 e^{(-0.05i)}] \text{ (Brown \& Foster, 1987)}$$

where:

- e – is the rainfall's kinetic energy per unit of precipitation (MJ/ha mm);
- i – is the rainfall's intensity (mm/h)

$$R = \sum EI_{30}$$

where:

- R – is the annual rainfall erosivity (MJ mm / ha h an).
- E – is the rain's kinetic energy (MJ/ha);
- I₃₀ – is the maximum 30 minutes intensity (mm/h).

Due to the difficulty of direct calculation of rainfall erosivity, as the rainfalls intensity is not currently recorded at the meteorological stations, indirect estimative models were elaborated on the basis of statistical relations between the erosivity and other parameters, easier to calculate: average annual precipitations, warm season average precipitations, maximum daily and hourly precipitations etc. (Rogler & Schwertmann, 1981, Diodato, 2004, Renard & Freimund, 1994 etc.). Although numerous, these relations cannot be applied for the Romanian territory because they are applicable for the areas they were elaborated for. For Romania, the rainfall erosivity is expressed differently, representing the average annual soil loss for the rainfall erosivity unit. The values of this parameter oscillate between 0,064 in the Western Plain and 0,207 in the Meridional Carpathians and, partially, the Getic and Curvature Sub-Carpathians (ICPA, 1987).

In the present study, we used the both the R factor zoned for the Romanian territory and the value of 450 present in the study of soil erosion at European level (Van der Knijff *et al.*, 2000).

Soil erodibility (K)

Soil erodibility, respectively soil's erosion susceptibility, can be determined on the basis of nomograms or calculating relations (Wischmeier, 1971, 1978), taking into consideration the granular-metric fractions of 0,002 – 0,1 mm, 0,1 – 2 mm, the organic matter content and the soil's structure and permeability. A more simple calculating relation was proposed by Römken *et al.* (1986) and revised by Renard *et al.* (1997).

$$[K = 0.0034 + 0.0405 \cdot \exp[-0.5(\frac{\log D_g + 1.659}{0.7101})^2]]$$

where:

- K: is the soil erodability (t ha h / ha MJ mm);
- D_g: is the geometric mean weight diameter of the primary soil particles (mm):

$$D_g = \exp(\sum f_i \cdot \ln(\frac{d_i + d_{i-1}}{2}))$$

where: d_i, respectively d_{i-1} are the maximum and minimum diameters of the particle size class i, and f_i is the sub-unitary percentage of the particle size class i.

The present study uses the erodibility value as specified by the ICPA standards (1987) and the derivate values from the above stated relation.

The C factor (the vegetation effect)

The C factor expresses the influence of vegetation upon soil erosion, and displays values between 0,02, in the forested areas and 1 for the uncovered soils. These values can be taken over from the standards elaborated by Motoc *et al.* (1975), or can be derived from satellite imagery, through calculation relations, depending on the normalised difference vegetation index (NDVI) (De Jong *et al.*, 1998):

$$C = 0.431 - 0.805 \text{ NDVI}$$

The main inconvenient in the use of satellite imagery is the fact that the derived values for NDVI and C are momentarily values, corresponding to the moment of image acquisition. Consequently, derivation of the C factor or other parameters should be based on a mosaic of images taken at different moments throughout the year.

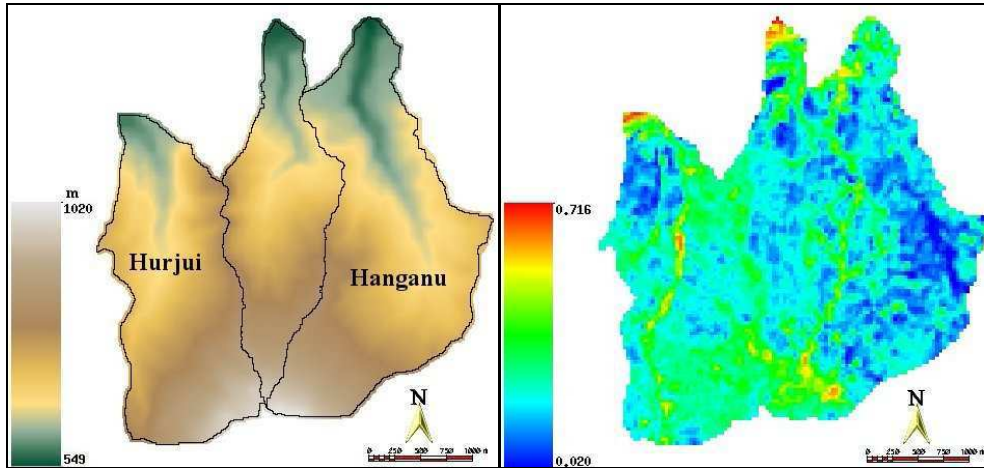


Fig. 1. The digital elevation model and the positioning of the studied hydrographic basins

Fig. 2. The C factor generated on the basis of NDVI, using LANDSAT imagery, conform to De Jong et al. relation (1998)

The LS factor (slope length and steepness factor)

Among all the factors, the slope length is probably the most difficult to compute when the soil erosion spatiality, within GIS, is to be considered. The slope length represents the plan projection of the distance between the onset of runoff and the point where runoff enters a channel larger than a rill or deposition occurs.

Inside USLE, the L factor is quantified using the standardized slope length (slope segment) raised to an exponent that takes values between 0,2 and 0,6:

$$L = (\lambda/22.13)^m$$

The USLE version adopted in Romania (Moşoc et al., 1975), the L factor is represented by the slope length raised at 0,3.

For RUSLE, the m exponent is determined with the following relation:

$$m = \beta / (1 + \beta) \text{ (Foster et al., 1997)}$$

$$\beta = (\sin \theta / 0.0896) / [3 (\sin \theta)^{0.8} + 0.56] \text{ (McCool et al., 1989)}$$

where θ is the slope angle.

Regardless the calculation relation, the problem of slope length spatialisation, within the GIS still remains. Apparently, the fittest approach resides in the substitution of slope's linear length (λ) with the upslope drainage specific area (A_s), that can be determined by multiplying flow accumulation, where a pixel value equals the number of the pixels drained from upslope, with the pixel's side:

$$L = 1.4 (A_s / 22.13)^{0.4} \text{ (Moore et al., 1993)}$$

$$L = (\text{Flow Accum} \cdot \text{resolution})^{0.6} \text{ (Desmet \& Govers, 1996)}$$

We notice the different values, for each author, for the multiplication and exponent coefficients. In the first case, the first relation, stated above, applied by *Van der Knijff et al.* (2000) for the spatial modelling of soil erosion at European level, uses the 1,4 value, while *Griffin et al.* (1988) recommends the 1,6 value for the estimation at pixel level. In the second case, the m exponent takes the 0,4 value, while other authors recommend the 0,6 value.

The use of specific upslope drainage area (A_s) does not generate concluding results within the GIS as far as the surface erosion is concerned (fig. 4). This parametrization seems to be more adequate for the concentrated erosion modelling or for sediment transport at the river channel level.

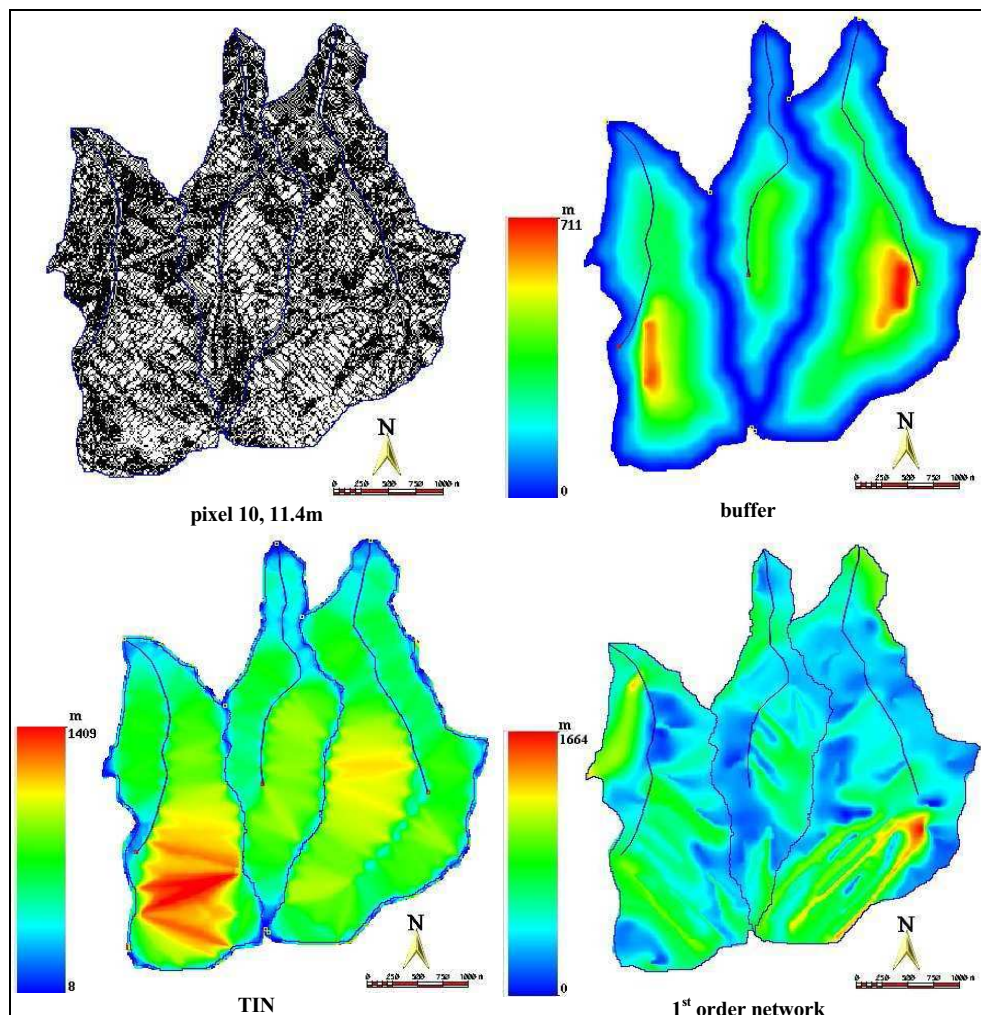


Fig. 3. Alternative possibilities for the quantification of flow length.

The present study also tests other manners of spatial expressions for the slope length factor (fig. 3):

- Using the *pixels' side as flow length*, differentiated on the basis of perpendicular or diagonal flow orientation as it enters the pixel. It is the simplest approach, even if, conceptually, it is less correct. The use of a same value as flow length assumes that the slope is made up by segments of equal dimensions, consequently, having different inclinations, which does not corresponds with reality. Nevertheless, certain studies demonstrate that this approach generates viable results if one uses the proper pixel dimensions.
- *Buffers* generation at successively greater distances starting from the main topographic ridges, followed by their interpolation to obtain a continuous spatial representation of the flow length. The procedure is simple for symmetric basins but it becomes more and more difficult for asymmetric or sinuous basins that require several corrections.
- Generation of a *triangulated irregular network* (TIN) between hydrographic ridges and the main valleys axis and the network's length sides values interpolation. The procedure generates errors along the ridges and, occasionally along the valleys axis, due to the presence of a dense network of small triangles. At the same time, the triangles' sides orientation do not coincide, very well, with the slope's maximum inclination direction. Nonetheless, the most important inconvenient resides in the constant values of the flow length along the triangles' sides, while in reality, these values should increase down-slope.
- Considering the flow length equal with *the length of the 1st order river segments* (or the length of the 1st order hydrographic basins), the approach becomes more *natural* compared with the preceding methods, but this method displays the same inconvenient as the TIN method, respectively the constant values along the river segments.

The spatial modelling of the slope steepness factor is more facile. The calculating relation for the USLE is:

$$S = 65.4 \sin^2 \theta + 4.56 \sin \theta + 0.0654$$

The USLE version, adopted in Romania, uses one of the below stated relations:

$$S = \theta^{1.5}$$

$$S = 1.36 + 0.97 \theta + 0.138 \theta^2.$$

where θ is the slope angle, expressed in percents.

In RUSLE, the slope steepness factor is evaluated differently depending on the slope angle (McCool *et al.*, 1987):

$$S = 10.8 \sin \theta + 0.03 \text{ pentru } \theta < 9\%$$

$$S = 16.8 \sin \theta - 0.50 \text{ pentru } \theta \geq 9\%$$

For the erosion resulting from snow melt, on slopes $\geq 9\%$, the second relation is substituted by (McCool *et al.*, 1987, 1993):

$$S = (\sin \theta / 0.0896)^{0.6}$$

A similar relation is proposed by *Moore et al.* (1993) for the quantification of the slope steepness factor regardless the inclination angle:

$$S = (\sin \theta / 0.0896)^{1.3}$$

This relation is used in combination with the L factor, evaluated on the basis of the specific upslope drainage area, in order to approximate the LS factor from RUSLE. The combination is also known as the Sediment Transport Capacity Index.

This manner of quantification for the LS factor was also tested within the present study, using both L as derivate of the flow accumulation and a fixed value of 50, which is the same as the one used in the erosional risk assessment study at the European level (*Van der Knijff et al.*, 2000). In the same respect, we also tested the calculating relation for Romania: $S = \Theta^{15}$.

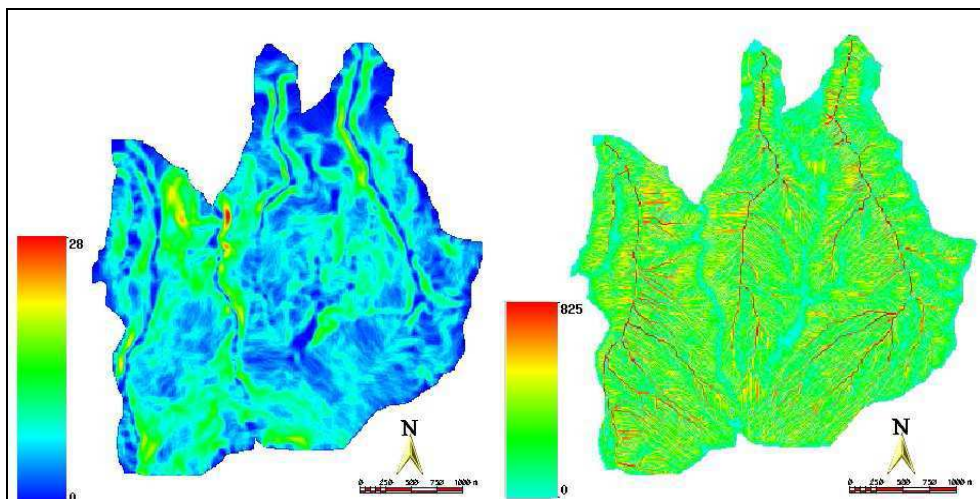


Fig. 4. The quantification of LS factor using the relation proposed by *Moore et al.*, 1993 (left) with a fixed value for L (50) and the specific upslope drainage area (right).

3. SOIL EROSION SPATIAL MODELING

The comparison between estimated average erosional values for the two hydrographic experimental basins (Hanganu and Hurjui) with the values measured by *Gaspar & Cristescu* (1987) emphasize the RUSLE equation as being optimal where the LS factor is quantified conformal with *Moore et al.* (1993) with a fixed value of 50m for the flow length, in which case the average error is minimum (2t/ha an). We also obtained good results by using buffers combined with the soil erodibility at the level of spatial soil unit. The greatest errors are generated by the use of pixels' side length as flow length and the specific upslope drainage area (fig. 5)

One can notice that the spatial distribution of erosion, obtained through different combinations of factors is similar and the most prominent factor is the slope steepness. The exception is given by the model that uses the specific upslope drainage area, which emphasizes most clearly the linear erosion, instead of emphasizing the surface erosion.

The main sources of errors, in the quantification of erosion through the models shown in table 1 are:

- The generalisation of the soil erodability, both by using an unique value at the basin level and by the use of soils map at small scale (1:200.000) for the spatial distribution of this parameter;
- The quantification errors of the flow length. No method, from the one we tested, is avoiding errors.
- The use of C factor generated on the basis of NDVI using a single LANDSAT satellite image, which catches only the momentarily situation of this parameter.

**Results regarding the annual average estimated erosion
using different quantification methods for the control factors,
compared with the annual measured average erosion.**

Table 1

Factors	Hanganu Basin – measured erosion: 28,8 t/ha an		Hurjui Basin– measured erosion: 38,1 t/ha an		Absolute average error
	Estimated erosion	Error	Estimated error	Error	
R=0.207; K=0.6; C-NDVI; L ^{0.3} buffer; S = $\theta^{1.5}$	19,1	9.7	30	8.1	8.9
R=0.207; K=0.6; C-NDVI; L ^{0.3} unique for the basin; S = $\theta^{1.5}$	27,6	1.2	42,6	-4.5	2.85
R=0.207; K=0.6; C unique for the basin; L ^{0.3} unique for the basin; S = $\theta^{1.5}$	36	-7.2	45,6	-7.5	7.35
R=0.207; K=0.6; C-NDVI; L ^{0.3} TIN; S = $\theta^{1.5}$	25,5	3.3	42	-3.9	3.6
R=0.207; K soil units; C-NDVI; L ^{0.3} buffer; S = $\theta^{1.5}$	27,7	1.1	42,4	-4.3	2.7
R=0.207; K=0.6; C-NDVI; L ^{0.3} pixel; S = $\theta^{1.5}$	13	15.8	19,6	18.5	17.15
R=0.207; K=0.6; C-NDVI; L ^{0.3} network order 1; S = $\theta^{1.5}$	27,2	1.6	41,9	-3.8	2.7
R=450; K=0.0438; C-NDVI; LS Moore et al (1993)	26,7	2.1	40	-1.9	2
R=450; K=0.0438; C-NDVI; LS with the upslope drained surface;	43,6	-14.8	65,6	-27.5	21.15

Another application regards the Călimani Massif even if, here, we did not dispose of erosion measurements to validate the models. Here, the sterile terrigenous masses left after the quarry abandon, constitute a risk element through its increased sliding and erosional potential. In order to estimate the erosion we used the DEM at a resolution of 5 meters (elaborated by dr. Stoica D.L.). The factors from the USLE equation were quantified according to the standards adopted for Romania (Moțoc et al., 1975, ICPA, 1987), mentioning that the L factor was evaluated on the basis of the 1st order network length.

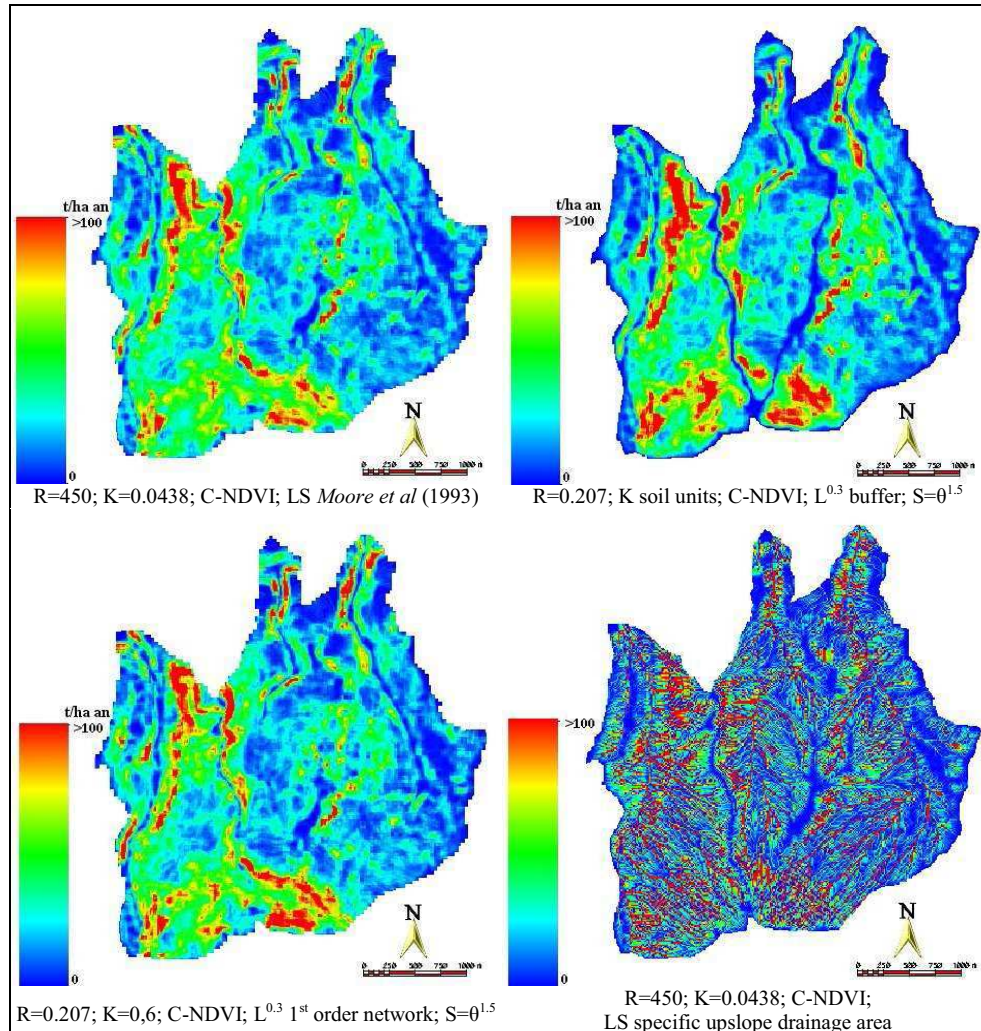


Fig. 5. Examples of spatial models for soil erosion obtained through different quantification methods of the control factors.

The spatial distribution of the estimated erosion (fig. 6) emphasizes, very clearly, the sterile terrigenous masses, the quarry and the degraded terrains surrounding the quarry which are characterized by a much greater erosion rate in comparison with the surrounding un-affected area, which displays values of 70-350 t/ha an, and, frequently, even above 500 t/ha an. These contrasts are also revealed by the chart showing the variation of the erosion rate along a topographic profile intersecting two sterile masses. The main peaks mark the inputs and outputs from the sterile masses, the erosion values suddenly increasing from 2-13 t/ha an to over 140 t/ha an, because of the lack of vegetation and the great erodability of these masses but also, as a result of steep slopes associated to sides of the sterile masses. Inside the sterile terrigenous masses, the erosional values vary greatly from 0 t/ha an to 100 t/ha an.

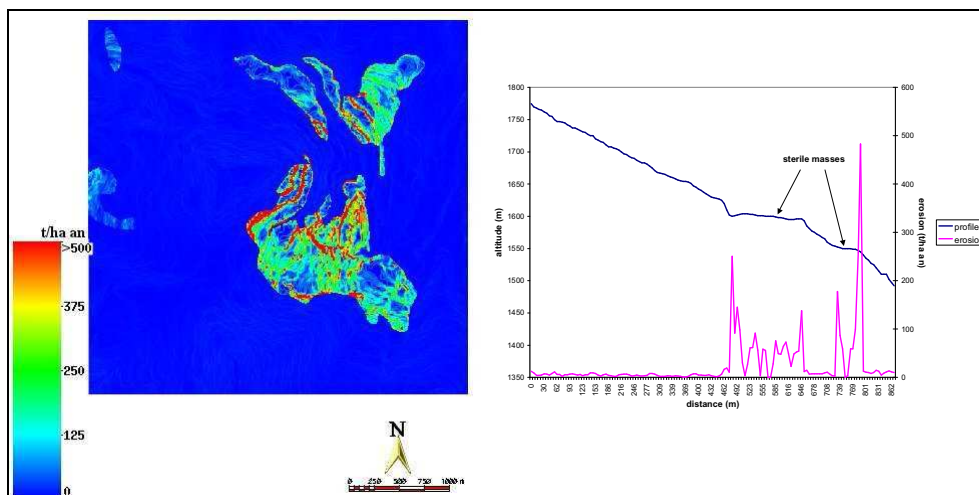


Fig. 6. The spatial model of erosion in the area of Călimani's sterile terrigenous masses (left) and the variation of estimative erosion rates along a topographic profile (right).

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