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Models for Estimating Soil Erosion in the Middle and Lower Vasluieţ Basin

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Abstract. In this paper, several models of estimating soil erosion have been compared, with a special emphasis on pixel-based calculation of soil loss. The paper describes and analyzes the differences between USLE, RUSLE 3D and USPED models, with an accent on the formula proposed by Moţoc *et al*. (1975). The materials used in the modeling process were the digital elevation model (DEM) at a 10m resolution, 1:10,000 soil maps created by OSPA Vaslui including the analytical data attached, ortophotoplans and LANDSAT images for C factor extraction. For each model, the necessary layers have been derived according to specifications provided by the original authors. Moreover, a review of the Romanian literature on the subject has been conducted. After calculating soil erosion according to each model, results were compared with the absolute values measured by various research centers and values obtained by other authors. It has been found that the values obtained are comparable with those of other authors, and even with those from runoff plots. The main conclusion of the paper is that the Romanian version of the USLE equation needs to be updated, and some factors such as rainfall erosivity and soil erodability re-evaluated. The use of such a version would make all the applications' results comparable.

Keywords: erosion models, USLE, RUSLE3D, USPED, ROMSEM.

INTRODUCTION

In 1978, Wischmeier and Smith developed one of the most important models for estimation of soil erosion: the universal soil loss equation (USLE). Because USLE is more suitable for estimating sheet erosion (FAO, 1996), the initial version was improved by numerous authors, resulting in several new models. We will describe only the Romanian version (ROMSEM, Moţoc *et al.,* 1975), because first of all we wanted to relate to other studies conducted in our country and secondly because the main differences between the models result from the computation of the topographical factor (slope length and declivity). The description of the RUSLE3D and USPED models can be found in Mitasova *et al.* (1996), Mitas *et al.* (1998) and Mitas and Mitasova (1999), and also in Niculiţă (2011).

In 1975, Moţoc *et al.* adapted the USLE equation to the conditions of our country, the formula being:

$$E= K\cdot L^m \cdot I^n \cdot S \cdot C \cdot Cs,$$

Where E is the mean annual rate of effective erosion (t/ha/y);

K= correction coefficient for rainfall erosivity;

L and I slope length (m) and declivity (%);

L^m – the influence of slope length, with m determined to be 0.3;

I^n= 1.36 + 0.97 i + 0,381 i^2, where i is the mean slope declivity;

S= correction coefficient for soil erodability;

C= correction coefficient for crop effect;

Cs= correction coefficient for the effect of erosion control measures.

The values of the **K factor** are extracted from a map of rainfall erosivity distribution published by Moţoc *et al.* (1975). A comparative study conducted by Stănescu *et al.* (1969)

revealed that rainfall erosivity value can be estimated with the help of simpler indicators than Wishmeier's EI_{30} index. Their conclusion was that the indicator of rainfall erosivity that included the intensity on 15 minutes of the rain (Hi_{15}) was an adequate indicator (correlations of 0.972-0.992 with erosion data from control plots). The index of rainfall erosivity is computed for each rainfall event and then by summing is obtained the monthly or seasonal value. The values of rainfall erosivity computed by the authors indicate deviations from the mean value of -47 up to +63. Data were considered valid for the entire area of influence established on arbitrary geometrical and mainly physico-geographical criteria. Another convention has been that of rainfall uniformity on the entire surface, while it is known that exceptional rainfalls usually cover reduced terrain surfaces. Thus from the beginning one can see that there are some problems regarding the values of the K factor: large standard deviations, arbitrary criteria in drawing the limits of different erosivity regions, and even improbable associations among different areas of Romania.

In the papers published in Romania, the K rainfall erosivity factor has been with a very few exceptions (Mihăiescu *et al.*, 2004; Patriche *et al.*, 2006) derived from the indirect estimative models elaborated on the basis of statistical relations between erosivity and other parameters, mainly from the map of Moţoc *et al.* (1975) or from the ICPA indicator 99 (1987).

Stângă (2011), analyzing the different ways of obtaining rainfall erosivity values, argues for the need to review such indicators, especially in Romania. Referring to indicator 99 from the ICPA methodology (1987), he points out situations that are hardly correct, such as similar values of the rainfall erosivity for plain units from the humid western part of the country, plain units from the much more arid south, as well as mountainous areas. Moreover, these indicators derived from climatic data have not been revised since their publication, and in this period of 25-35 years more data have been collected and better techniques of spatial modeling have been derived, which could clearly improve the results.

In the original version, **the S factor** has values from 0.6 to 1.2, established based on erosion data from runoff plots with the help of infiltrometers. Moţoc *et al.* (1975) established six classes (describing soil erosion, cohesion and structural state), which were further developed to include in the description the soil types, according to texture, structure and erosion state. Soil erodibility can also be determined from nomograms or calculating relations (Stângă, 2004 inventoried and analyzed 10 such equations). In Romania, most of the authors have used the methodology elaborated by ICPA (1987) for deriving the factor values.

Being an equation constructed for arable terrains, **the original C factor** has values of 0.25-0.6 according to the different combinations of crops cultivated. Later (Moţoc *et al.* 1979, Moţoc and Sevastel, 2002) these values have been extended to include different types of land use categories. Also, **the Cs factor**, which takes into account the anti-erosion efficiency of the management system practiced, has values differentiated according to such systems (for example contour farming) and the terrain slope. So, for studies at larger scales, where aerial or satellite images are used to derive land use categories, Moţoc *et al.*'s equation does not specify values of the C indicator for all of these. Thus, several authors have used values from literature (eg. Lee and Lee, 2006) or derived from satellite imagery, through calculation relations, based on the normalized difference vegetation index (NDVI).

Hickey (2000) mentions that there are problems with most of the methods currently available for the calculation of the topographical factor (LI), while Patriche *et al.* (2006) state that among all the factors **slope length** is probably the most difficult to compute. They present several such methods used for quantifying the L factor, most of which use slope length (slope segment) raised to an exponent that takes values between 0.2 and 0.6 (0.3 in the Romanian methodology). Garcia Rodriguez, and Gimenez Suarez (2010), Hickey (2000), Van Remotel *et al.* (2001), among others debated this problem of deriving the LS factor. In time, the algorithms used to calculate slope length have been developed to include grid based methods (Hickey *et al.*, 1994), unit stream power theory (Mitasova *et al.*, 1996; Moore *et al.*, 1993), contributing area (Desmet and Govers, 1996), some of them giving birth to models such as RUSLE3D or USPED.

Patriche *et al.* (2006) have tested several methods of spatial expressions for the slope length factor:

- using the pixels' side as flow length;
- buffers generated at successively greater distances starting from the main topographic ridges, followed by their interpolation to obtain a continuous representation of the flow length;
- generation of a triangulated irregular network between ridges and the main valleys axis and the network's length sides values interpolation;
- considering the flow length equal with the length of the 1st order river segments.

They reached the conclusion that the fittest approach resides in the substitution of slope's linear length with the upslope drainage specific area (As), 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 (Moore *et al.*, 1993). In their study, the largest errors were generated by the use of pixels' side length as flow length and the specific upslope drainage area.

In the revised studies different approaches have been used for computing the topographical factor, beginning with classical determination of the slope length and angle on the DEM and ending with the formulas of Moore *et al.*, 1993 (Arghiuş and Arghiuş, 2011; Mihăiescu *et al.*, 2004), Mitasova *et al.*, 1996 (Bilaşco *et al.*, 2009; Filip S., 2009; Ştefănescu *et al.*, 2011), Desmet and Govers, 1996 (Anghel *et al.*, 2007; Anghel and Bilaşco, 2008; Anghel and Todică, 2008).

One can see from the above mentioned that the application in GIS of the Romanian version of USLE raises some problems regarding the choice of indicators. More precisely, some factors involved in the equation have to be derived in different modes than those originally specified by the authors. Patriche *et al.* (2006) also mention that the factors intervening in the Romanian version of USLE (R, K, LS) differ substantially 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. Thus, we can hardly speak of applications of the ROMSEM model on areas larger than parcels.

MATERIALS AND METHODS

The medium and lower Vasluieţ basin is located in the eastern part of Romania, in the Central Moldavian Tableland. Altitudes vary between 426.8 m and 79.6 m, the mean being of 188 m. Surface deposits are represented mainly by clays, sandy clays and sands, thus conditioning a dominance of the sculptural relief and an appreciable extension of surface erosion and landslides.

Land use is dominated by arable terrains, which occupy 46%. The second category is that of grasslands, simple or mixed with brushes (26%). Along time, surfaces occupied by agricultural terrains have increased, but not always on the most favorable terrains, situation that led to an acceleration of degradation processes.

The soil cover includes chernozems (50.55% of the arable surface), but the erosion and slope processes have led to a large development of regosols (17.82%) and erodosols (6.40%).

The study focused mainly on two erosion estimation models: USLE (adapted to the Romanian methodology) and RUSLE3D, each with two versions according to the choice of factors. In addition to these models, we also computed the USPED model for erosion / deposition of Mitasova and Mitas (1998), which predicts the spatial distribution of erosion and deposition rates for a steady state overland flow with uniform rainfall excess conditions for transport capacity limited case of erosion process. Because the USPED model does not predict erosion, but mainly the distribution of erosion/deposition areas, we combined it with a RUSLE version to eliminate from the calculation the deposition areas.

For deriving the factors needed in computing the models, were used the topographic maps at scale 1:5000, aerial photography, satellite imagery (LANDSAT) and soil surveys studies (including soil maps) from OSPA Vaslui. We used digitized contours and elevation points to interpolate the DEM at a 10 meter resolution in respect of methodology proposed by Mitasova *et al*. (1996), using *v.surf.rst* module from GRASS software and *tension=default according to scale* and *smoothing=0.5* as parameters. The choice of applying smoothing was determined by the need to obtain, as much as possible, an error free elevation model. The slope gradient was computed both in degree and percent according to models requirements. The soil and land use maps were updated with attributes representing erosion coefficients and converted to raster layers at the DEM resolution. In order to compute the models without flat surfaces and inhabited areas, we created a mask in which the floodplains, plateaus and rural/urban areas were excluded.

In what regards the choice of the factors entering the formula, the approach went on two directions.

Rainfall erosivity (K) value was constant and equal to 0.144 (ICPA, 1987). The study area is located at the limit between the values 0.100 and 0.144 on the ICPA map, but taking into consideration that Stângă (2011) demonstrated with the help of the Modified Fournier Index that the area is characterized by medium rainfall erosivity, the higher value was chosen for the entire basin.

Slope length (L^m) was determined differently according to the model used. For the USLE model, it was determined using the module from SAGA GIS, the value of the m factor being 0.3. In the RUSLE3D approach, the slope length factor was replaced by upslope contributing area and combined with slope declivity. Mitasova *et al*. (1996) derived a simpler, continuous form of the equation:

$$LS(\mathbf{r}) = (m+1)\ [\, A(\mathbf{r}) / a_0 \,]^m\ [\, \sin b(\mathbf{r}) / b_0 \,]^n$$

where $A[m]$ is upslope contributing area per unit contour width, b [*deg*] is the slope, m and n are parameters, and $a_0 = 22.1m$ is the length and $b_0 = 0.09 = 9\% = 5.16deg$ is the slope of the standard USLE plot. The conclusion of the authors is that the upslope area-based factor reflects better the impact of concentrated flow on increased erosion.

For USLE, slope declivity factor (I^n) was computed according to Moţoc *et al*.'s (1975) formula using the slope computed in percent.

For soil erodability (S) the ICPA (1987) standards were used, taking into account the soil type, texture and surface erosion degree, based on the 1:10000 soil maps from OSPA Vaslui. Values vary between 0.6 for the less erodable soils and 1.1 for those with the highest susceptibility to this process.

The effect of vegetation was assessed in two ways, first based on the NDVI index derived from Landsat satellite images, using the formula proposed by Van der Knijff *et al.* (2000):

$$C = \exp\left[-\alpha * \frac{NDVI}{(\beta - NDVI)}\right]$$

where: α and β are coefficients with the values of 2, respectively 1.

After calculating the equation, the image was resampled to match the resolution and extent of study area.

The second approach was according to the Romanian methodology. Land use classes were determined from the 1:5000 aerial images from 2009, and values were given according to Moţoc and Sevastel (2002). In some cases were computed medium values for land use classes not found in literature: 0.001 for forests, 0.2 for complex arable terrains and pastures mixed with brushwood, 0.3 for grasslands, 0.5 for orchards, 0.6 for degraded orchards and arable terrains, 0.7 for vineyards and 0.8 for degraded vineyards.

Factor P, the effect of management, has been considered equal to 1, due to the scale of the approach.

Because there are no measured values of erosion rates in the basin, an attempt of validating the models was done using basic statistic parameters and distributions of the obtained values on land use categories, relief forms and some control plots.

RESULTS AND DISCUSSIONS

The statistical data for the five erosion models computed (Tab. 1) show small differences in what regards the maximum values. Taking into account that the maximum values are associated with very small surfaces with large slopes (landslide scarps), the most relevant statistical value remains the mean. Analyzing these data, we observe a clear separation among the models: USLE give mean values of 7.78-8.16 t/ha/y, while RUSLE3D versions give higher values, of 19.24-22.24 t/ha/y. Combining the RUSLE and USPED rasters, we can see an improvement in the data, in the sense of a reduction of the mean values up to 14.6 t/ha/y.

Tab. 1

Statistical values regarding soil erosion estimates (t/ha/y) for the five versions of models applied

	USLE (factor C aerial images)	RUSLE3D (factor C aerial images)	USLE (factor C NDVI)	RUSLE3D (factor C NDVI)	USPED+RUSLE
Max	315.3	392	208.4	496.65	392
Min	0	0	0	0	0
Med	7.78	19.24	8.16	22.24	14.6
Median	5.65	15.55	5.46	15.45	9.42
Mode	0.03	0.04	0.02	0.06	0.04
St. dev	8.68	18.74	9.45	24.42	17.89

Because of the different choice of factors, the effective erosion values obtained by the authors who approached USLE modeling in GIS are also different. The mean values vary from 0.0 t/ha/y (Prefac 2008 for the sector of Lower Siret Plain of the Râmna basin) up to 4.57 t/ha/y (Patriche 2005, Central Moldavian Tableland) and 5.04 t/ha/y (Prefac 2008, the depression area of the same basin). The highest values, and ones of the few validated, have been obtained by Patriche et al. (2006) for the mountainous basins of Hurjui and Hanganu (38.1, respectively 28.8 t/ha/y). Most of the studies have obtained small mean values of erosion (0.5-2 t/ha/y), most probably because of taking into account the entire study regions, including areas without erosion such as floodplains. More, most of the studies conducted in

Romania specify that percentages of the regions studied varying between 60 (frequently 80) are characterized by an effective erosion rate lower than 1 t/ha/y (Anghel et al. 2007, Anghel and Todică 2008, Prefac 2008, Horvath *et al*. 2008, Bilaşco *et al*. 2009, Niacşu 2009, Ştefănescu *et al*. 2011, Arghiuş and Arghiuş 2011).

Measured values of soil erosion in NE Romania reach for example 4.8 t/ha/y. In the Scobâlţeni basin, during 1980-2010 the mean erosion rates have been of 18.17 under bare fallow, 8.93 under sunflower, 8.39 under maize and 1.62 under wheat (Bucur *et al.*, 2011). Popa et al. (2010) have determined averages of soil losses at Perieni of 0.16 to/ha/y for brome grass, 0.86 to/ha/y for wheat, 9.30 to/ha/y for corn and 43.12 to/ha/y for black fallow. Sevastel *et al*. (2010) mention some erosion figures for Aldeni - Buzau, for situations including standard runoff plots of 40 m^2 and 100 m^2, with loamy textured chernozems and mean annually precipitation of about 450 mm (for the period 1995-2010). For slopes of 15% and 20%, the soil losses have been of 40.95 – 97.9 t/ha/y in the case of bare soil, 13.1-32.9 for corn, 2.9-3.8 for winter wheat, and 0.2-0.3 for perennial grass.

Having in view the comparison of our data with those obtained by other authors, and also the variation of the measured soil erosion rates, we appreciate the USLE (ROMSEM) method as giving more realistic values in case of sheet erosion.

The map of mean annual soil losses produced by surface erosion (fig. 1) and its corresponding histogram show that 70.5% of the basin (21,789 ha) is characterized by unappreciable and weak erosion. Moderate erosion affects 21.2% of the region's surface, while strong and very strong erosion affect only 7.22, respectively 0.98%.

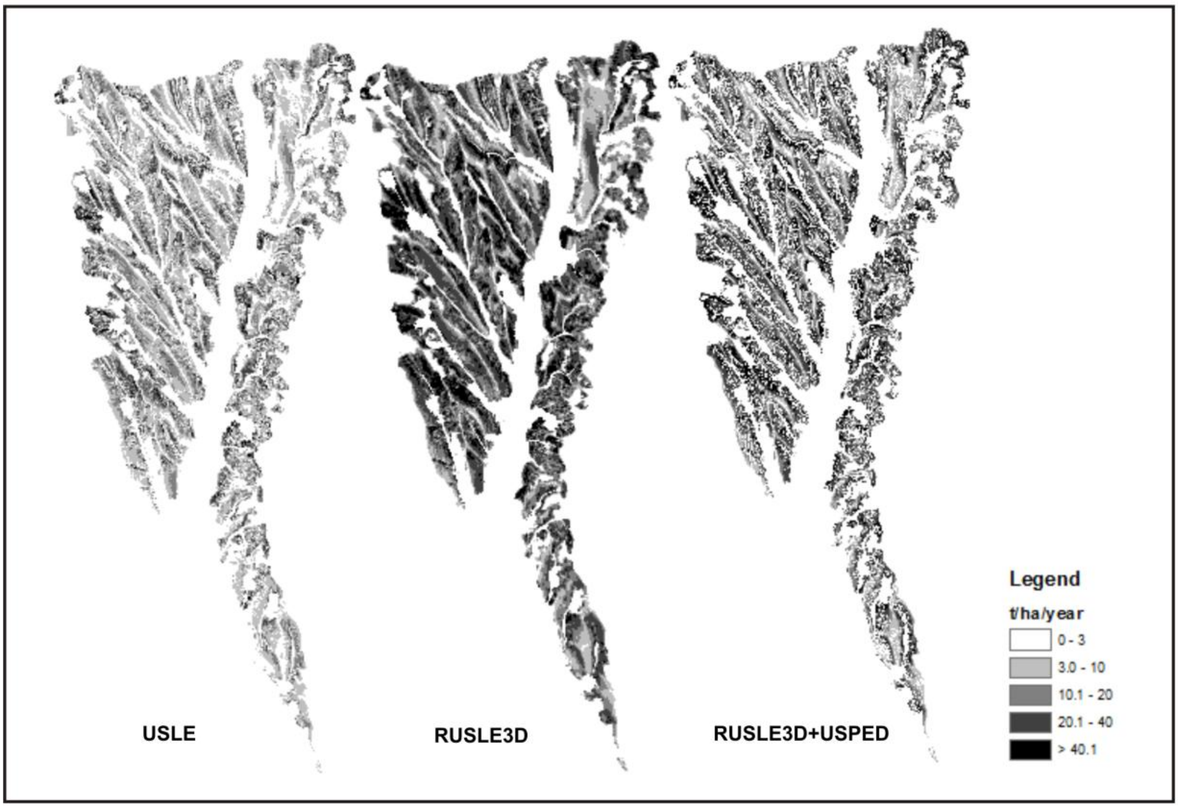

Fig. 1. Graphical representations of some of the erosion models compute

The most affected areas are the degraded orchards and vineyards, where erosion rates exceed 20 t/ha/y (Tab. 2). Pastures are on the overall characterized by an erosion rate of 9.6 t/ha/y, and arable terrains by 8.82 t/ha/y.

Tab. 2

Medium values of soil erosion (t/ha/y) on land use categories

	USLE (factor C aerial images)	RUSLE3D (factor C aerial images)	USLE (factor C NDVI)	RUSLE3D (factor C NDVI)	USPED+ RUSLE
Degraded orchards	23.4	52.73	12.97	35.3	40.39
Degraded vineyards	19.6	46.88	11.6	30.85	35.82
Vineyards	11.07	29.25	6.24	16.93	22.6
Pastures	9.6	21.97	11.15	31.29	16.33
Arable terrains	8.82	22.57	7.76	21.08	17.15
Complex arable	8.67	15.51	9.89	28.46	10.85
Pastures with brushwood	7.61	17.7	13.12	36.14	12.07
Orchards	5.05	13.55	3.06	8.49	9.63
Forests	0.32	0.71	0.31	0.76	0.32

Computing the erosion risk classes on landform types (extracted with the help of the Digital Elevation Model), the tendency is clear. Erosion rates increase from landforms with low declivities such as terraces or hilltops to those with higher declivities (cuesta escarpments, slopes) (Fig. 2). Most of the terrains characterized by strong erosion (20-40 t/ha/y) are found on north- and west-facing cuestas, as well as on weakly or strongly degraded slopes. The few areas with very strong erosion are to be found on cuesta escarpments.

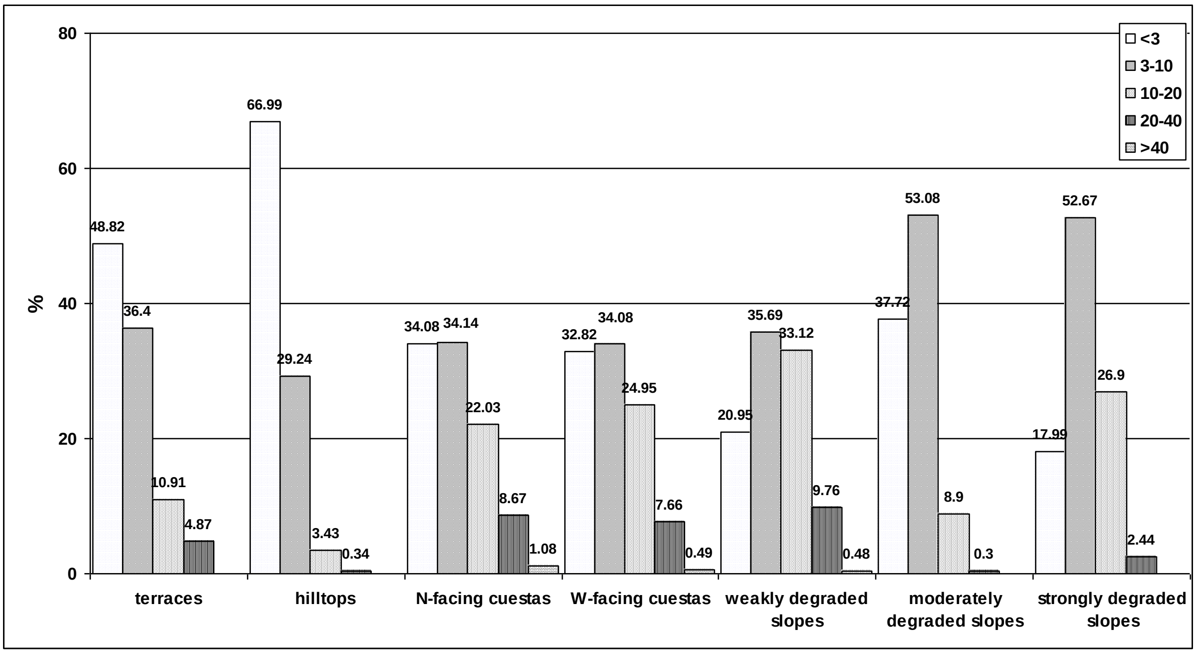

Fig. 2. Distribution of erosion risk classes on types of landforms

Besides the comparison with values found in literature, an attempt of validating the results of the models was made by selecting a few plots characterized by different agricultural management types (Tab. 3). It can be seen that the results are quite valid. As it was expected, the highest erosion values are found in the case of a high slope up-and-down hill tillage system and of a pasture. In the opposite corner are two cases of good management: stripped crops and contour tillage, cases in which estimated erosion enters the limits of acceptable soil losses (6-8 t/ha/y, Moţoc *et al.*, 1975).

Tab. 3

Maximum and medium values of soil erosion (t/ha/y) for the validation plots

	USLE (factor C aerial images)		RUSLE3D (factor C aerial images)		USLE (factor C NDVI)		RUSLE3D (factor C NDVI)		USPED+ RUSLE	
Validation plots	max	med	max	med	max	med	max	med	max	med
Up-and-down hill tillage	65.2	23.61	56.7	20.15	142.9	56.48	122.86	53.68	142.9	44.02
Pasture	33.03	10.7	67.1	15.5	48.54	20.92	151.9	39.57	48.11	15.37
Orchard	25.85	7.27	43.01	5.61	89.05	22.9	102.7	17.72	81.92	15.62
Up-and-down hill tillage	63.7	7.26	42.4	7.25	135.5	22.44	222.6	23.41	135.5	17.08
Stripped crops	44.64	7.23	49.7	5.78	158.8	20.07	142.86	16.51	137.8	16.51
Contour tillage	17.86	6.25	23.7	8.27	44.16	15.59	61.9	20.49	44.16	11.36

CONCLUSION

Analyzing the result of these models, we can conclude that the obtained values can be compared with those from test plots, but certain specifications need to be made. Thus, the USLE model is suitable only for small areas (parcels, plots, etc.) and the values are representing the soil loss through sheet erosion. For landscape scale, where other features appear, such as landslides, abrupt slopes, small valleys, etc. the RUSLE3D is more realistic. In addition, values represent rill and interrill erosion. Combining the RUSLE3D with USPED model, we can obtain a good representation of areas most susceptible to be affected by erosion. Better result can be obtained if NDVI is used instead of digitized land use for vegetation influence because of better temporal resolution. Using satellite images also presents the advantage of vegetation influence value per pixel, which is more accurate than the standard method.

On the overall, as Horvath *et al*. (2008) affirmed, such models inherently include errors, because they are based on empirical equations. The use of such models is best to be resumed to identifying areas at risk, where management actions have to be taken. In order to reach a GIS-applicable method for better estimating soil loss by erosion, the Romanian adaptation of the USLE equation needs a re-evaluation of some of the factors.

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