ASSESSMENT OF EROSION HAZARD IN TORRES MUNICIPALITY OF LARA STATE (VENEZUELA) BASED ON GIS

ONELIA ANDRADE, MARTIN KAPPAS and STEFAN ERASMI

SUMMARY

The Revised Universal Soil Loss Equation (RUSLE) model was used to predict soil erosion hazard in the Torres municipality, Lara, Venezuela. Rainfall-runoff erosivity (R) values indicated low erosion potential. The soils have moderately low to high erodability (K), it being larger in the agricultural zone. The values of the LS factor are relatively low, since the study area is mainly morphologically flat. Cell-by-cell multiplication of the maps of R, K and LS factors resulted in a map of potential erosion. A similar procedure, adding the factors crop and management (C), and conservation practices (P) was used to estimate actual erosion. The smallest actual erosion values of soil losses were registered in forest zones and where agricultural practices are carried out. Actual erosion had a range of 0-2558t·ha^{-1} per year, but more than 72% of the area is under very low water erosion hazard, and is highly suitable to rain fed agriculture. Areas susceptible of erosion with a soil loss >12t·ha^{-1} per year are found primarily in the higher basin, or where there is sparse cover. The percentage of high sustainability for agricultural purpose amounted to 100% in the agricultural area. In accordance, the zone can be used continuously with annual mechanized cultivations without conservation practices. The results support that the RUSLE under GIS environment, coupled with digital elevation model (DEM) data and remote sensing, are powerful tools for both qualitative and quantitative assessment of soil erosion in a hydrographical basin.

The Torres municipality is one of the most important regions for agricultural production in the Tocuyo River Basin, Venezuela. For planning soil conservation strategies in the basin, an important aspect to consider is the identification of specific high-priority areas for the implementation of management practices. Thus, the evaluation and mapping of the regional erosion hazard is increasingly needed by national and local agencies related to agricultural activities and environmental protection.

Erosion Hazard: Definition and Basic Concepts

Defined as the loosening or dissolving and removal of earthy or rock materials from any part of the earth's surface (ASCE, 1970), erosion is a process of detachment and transportation of soil materials by erosive agents such as wind, rainfall or runoff (Foster *et al*., 1997). Runoff erosion can take place in non-concentrated (sheet) flow, in rills or gullies. Soil eroded from a given area is defined in terms of the rate of erosion. Total sediment outflow from a watershed per unit time is called sediment yield (Novotny and Chesters, 1989). Factors affecting water erosion are climate, topography, soil, vegetation and anthropogenic activities such as tillage systems and soil conservation measures (Foster *et al*., 1997).

Erosion Hazard Evaluation and Models

The most commonly used method of predicting the average soil loss rate from agricultural lands is

KEYSWORDS / Erosion Hazard / GIS / RUSLE / Suitability Ratings / Venezuela /

Received: 23/01/2009. Modified: 05/04/2010. Accepted: 07/04/2010.

Onelia Andrade. Agronomist, Universidad Centroccidental Lisandro Alvarado, Venezuela. Master in Soil Sciences, Universidad Central de Venezuela. Ph.D. in Natural Sciences, Georg-August University, Goettingen, Germany. Researcher, Instituto de Investigaciones Agrícolas (INIA-Yaracuy), Venezuela. Address: Estación Local Yaritagua, Km 3 vía El Rodeo, Yaritagua, Edo. Yaracuy. Apartado Postal Nº 177. e-mail: oneliaandrade@yahoo.es

Martin Kappas: Geophysicist, Cologne University. Ph.D., Geology and Geography, Mannheim University, Germany. Professor, Goettingen University, Germany. e-mail: mkappas@uni-goettingen.de

Stefan Erasmi. Diploma and PhD in Geography, Goettingen University, Germany. Senior Scientist, Goettingen University, Germany. e-mail: serasmi@uni-goettingen.de

the Universal Soil Loss Equation (USLE; Irvem *et al*., 2007). Renard *et al*. (1997) have modified the equation into a Revised USLE (RUSLE) by introducing improved means of computing the soil erosion factors. RUSLE is an empirical erosion model designed to predict the longtime average annual soil loss (A) carried by runoff for specific field slopes in specified cropping and management systems, as well as from rangeland. The RUSLE is written as

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

where A: soil loss in $t \cdot ha^{-1}$ per year over a period selected for R, usually on a yearly basis; R: rainfall-runoff erosivity factor expressed in $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1}$ per year; K: soil erodability factor expressed in $t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$; L: slope length factor; S: slope steepness factor; C: cover and management factor; and P: conservation practices factor. L, S, C and P are dimensionless.

Determining RUSLE Factor Values

Rainfall-runoff erosivity (R) factor

Rainfall-runoff erosivity is estimated using the measured EI_{30}: total energy of each storm (E) times the maximum 30min intensity (I_{30}) of the storm, added for all storms in an N years period and divided by the number of years in record (Renard *et al*., 1997). It is expressed as

$$EI_{30}= (\Sigma(E \times I_{30})) / N \tag{2}$$

These values are generally obtained from rain gauge graph analysis (Silva, 1995). Normally, there is a lack of continuous data from pluviographs; therefore, to overcome this problem the EPIC (Environment Policy Integrated Climate, previously named Erosion Productivity Impact Calculator; USDA-ARS-BRS, 1997) simulation model is used to obtain approximations of the erosivity. EPIC is based in empirical equations that calculate duration and intensity of the rain according to daily precipitation. EPIC simulated daily erosivity values were evaluated by comparison to rain gauge graph analysis in some agricultural zones of Venezuela (Paredes and Silva, 2004). Daily erosive energy of the zone was obtained following the methodology of Wischmeier and Smith (1978) and was accumulated to obtain annual total values and monthly average values. For the same period of registry of erosive energy, daily precipitation information was used in the EPIC model, obtaining daily simulated values in each locality, and these were accumulated in the same way as the measured values. Simulated and measured values were compared statistically in terms of efficiency of simulation, coefficient of agreement and regression, and no significant difference was found between the two methods. The authors concluded that in Venezuela the EPIC model can be a substitute adapted to the analysis of bands, so as to obtain annual values of erosivity in agricultural zones where rains are distributed in bimodal form; as a result regression equations were generated to calculate the erosivity in some zones of Venezuela. The following regression equation was generated in the proximity of the Torres Municipality:

$$EI= 0.016(P)^2 + 1.2433(P) + 17.283 \tag{3}$$

where P: monthly precipitation (mm)

Soil erodability (K) factor

To estimate K values, the most widely used and frequently cited relationship is the soil-erodability nomograph (Wischmeier *et al*., 1971). The nomograph comprises five parameters: percent of modified silt (0.002-0.1mm); percent of modified sand (0.1-2.0mm), percent of organic matter (OM), and classes for structure (s) and permeability (p). The following relationships are very useful for predicting K values of soils for which data are limited (such as lack of information about the very fine sand fraction or OM content), the textural composition is given in a different classification system, and when there are no data about structure and permeability.

$$K= 7.594\ (0.0034 + 0.0405 \exp(-1/2(\log(Dg) + 1.659/0.7101)^2)) \tag{4}$$

$$K= 7.594\ (0.0017 + 0.049 \exp(-1/2(\log(Dg) +1.675/0.6986)^2)) \tag{5}$$

$$K= 0.0035 + 0.0388 \exp(-1/2(\log(Dg) +1.519/0.758)^2)) \tag{6}$$

where $Dg(mm)= \exp\ (0.01\ \Sigma f_i \ln m_i)$ (7) and Dg: geometric mean particle diameter; fi: primary particle size fraction in percent, and mi: arithmetic mean of the particle size limits of that size (Poesen, 1992).

Topographic factors (L and S)

The effect of topography on erosion is accounted for in RUSLE by the LS factor. Erosion increases as slope length increases, and it is considered as the slope length factor (L). The slope steepness factor (S) reflects the influence of slope gradient on erosion. Plot data used to derive L have shown that average erosion for the slope length λ (in m) varies as

$$L = (\lambda/22.13)^m \tag{8}$$

where 22.13: unit plot length (in m; Wischmeier and Smith, 1978), λ: horizontal projection of slope length, and m: variable slope-length exponent. Eq. 9 (Foster *et al*., 1997) defines m as

$$m= \beta / (1 + \beta) \tag{9}$$

where β: ratio of rill erosion caused by flow to interrill erosion, which is principally caused by raindrop impact. Values for the β ratio have been computed (McCool *et al*., 1989) as

$$\beta= (\sin \theta / 0.0896) / (3.0(\sin \theta)^{0.8} + 0.56) \tag{10}$$

where θ: slope angle in degrees. Given a value for β, a value for the slope-length exponent m is calculated from Eq. 9.

The slope steepness factor (S) is evaluated using the following equations for steepness categories, Eqs. 11 and 12 for slope lengths >15 feet (4.56m) and Eq. 13 when the slope length is <15 feet (McCool *et al*., 1987).

$$S= 10.8 \sin\theta + 0.03 \text{ when steepness } <9\% \tag{11}$$

$$S= 16.8 \sin\theta - 0.50 \text{ when steepness } \geq 9\% \tag{12}$$

$$S= 3.0\ (\sin\theta)^{0.8} + 0.56 \tag{13}$$

In erosion prediction, factors L and S are usually evaluated together, and values can be calculated from a grid-based digital elevation model (DEM), combined with GIS (Desmet and Govers, 1996).

Crop and management (C) factor

Mutchler *et al*. (1982) indicated that the general impact of cropping and management on soil losses can be divided into a series of subfactors. Each sub-factor contains cropping and management variables that affect soil erosion and are expressed as functions of one or more variables, including the prior-land-use (PLU), canopy cover (CC), surface cover (SC), surface roughness (SR), and soil moisture (SM). Based on new descriptions of cropping and management practices and their influence on soil loss (Laflen *et*

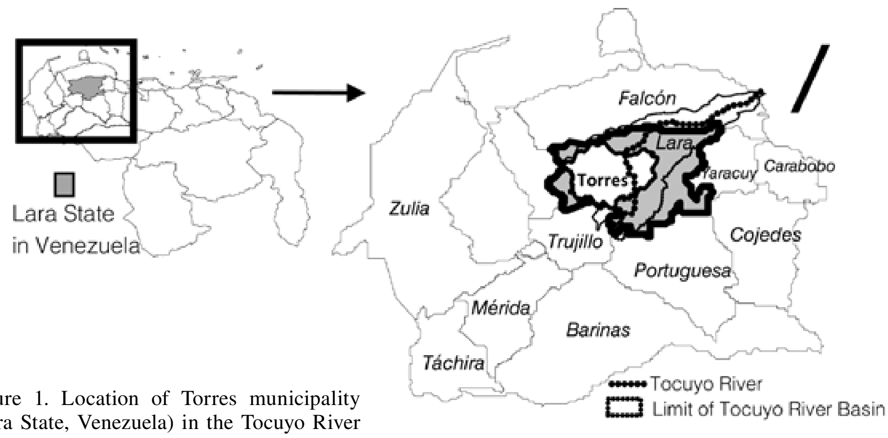

Figure 1. Location of Torres municipality (Lara State, Venezuela) in the Tocuyo River Basin.

al., 1985) soil loss ratios (SLR) are computed as

$$SLR= PLU \times CC \times SC \times SR \times SM \quad (14)$$

Conservation practices (P) factor

For cultivated land, the support practices considered include contouring (tillage and planting on or near the contour), strip cropping, terracing, and sub-surface drainage. On dry land or rangeland areas, soil disturbing practices on or near the contour that result in storage of moisture and runoff reduction are also used as support practices (Renard *et al.*, 1997).

Soil erosion and GIS

The combined use of GIS and USLE/RUSLE has been proven to be an effective approach for estimating the magnitude and spatial distribution of erosion (Fernández *et al.*, 2003; Hoyos, 2005; Erdogan *et al.*, 2006; Fu *et al.*, 2006; Irvem *et al.*, 2007; Saroingsong *et al.*, 2007). Within a raster-based GIS, the RUSLE model can predict potential erosion on a cell-by-cell basis, which is advantageous when attempting to identify the spatial patterns of soil loss present within a large region (Díaz, 2005). The GIS can then be used to isolate and query these locations to yield vital information about the role of individual variables in contributing to the observed erosion potential value (Oñate, 2004; Barrios, 2002).

Objective

The general objective of this work was to develop GIS-based soil erosion hazard (actual and potential) maps of the Torres Municipality, Venezuela, based on the RUSLE model; and to determine the suitability ratings for soil erosion hazard in a land evaluation according to FAO (1985) and Páez (1994).

Study Area

The Torres municipality is located within the Tocuyo River Basin in west Lara state, Venezuela, at 9°40'-10°34'N and 69°36'-70°52'W, covering an area of ~6954km^2 (Figure 1). Elevations range 416-2324masl. The climate is warm, except for the mountains, with accentuated irregularity of the rain regime and with negative water balance through the year. It shows a seasonal pattern of bimodal rain, distributed in April-May and August-November with the maximum in October. The dry station varies according to the humidity province and is known as *veranito de San Juan*. Water balance establishes certain changes in the humidity regime, giving origin to humidity provinces or climatic demarcations. The average annual precipitation ranges from 548 to 2334mm, temperatures of 19-28°C and evapotranspiration between 725 and 1250mm. During the day, sun radiation generates a thermal energy of 1.94cal·cm^{-2}·seg^{-1}. In general, the vegetal cover of the area is not dense and the vegetal species are of low bearing or height. The soils have low permeability, favouring erosive processes. Land uses are mainly agricultural, dominated by horticulture, sugar cane (*Sacharum* spp.), grape (*Vitis vinifera*) and subsistence agriculture (Andrade, 2007).

Material and Methods

Individual GIS files were built for each factor in the RUSLE. Each factor was considered as a thematic layer. These layers were spatially overlaid and combined by cell-grid modelling procedures in ArcGIS 9 (ESRI, 2005) to predict soil loss in the spatial domain and produce a resultant layer of a composite map of erosion hazard intensity in t·ha^{-1} per year. This intensity map was classified into different priority classes upon maximum acceptable limits of estimated soil loss (FAO, 1985; Páez, 1994). From these data, simple algorithms were used to classify the area into different hazard zones. The various layers of data were of mixed types (resolution, scale, units, coordinates) and were brought to common coordinates before being processed together.

Rainfall-runoff erosivity (R) factor

The study utilized data from 33 meteorological stations. The precipitation was derived with daily values from 20 years (1985-2005). In the area, most of the meteorological stations do not have the information required by the original Eq. 2; thus, factor R was determined by calculation based on Eq. 3, applied to precipitation events >12.5mm. The values of R obtained were transferred to ArcGIS.9 and an attribute table was created. For the mapping procedure, the point theme of R was generated. Then, the surface map was produced from development point themes using the nearest neighbor Kriging interpolation technique, with 12 neighborhoods. The cell size for interpolation was 30m. In view of the effect of elevation on the actual amount of precipitation, R values were site-specifically corrected using a DEM. The resultant map for the R factor was made with a weighted average of both methods. Additionally, rain aggressiveness was characterized with the modified index of Fournier (IMF) proposed by Arnoldus (1980), wich determines the rain capacity or power to cause erosion, calculated as

$$IMF= \Sigma P^2/P \quad (15)$$

where P^2: monthly precipitation (mm), and P: annual precipitation (mm).

Soil erodability (K) factor

The K factor map was prepared from the soil map (MARN, 1993; Andrade, 2007) and its attri-

TABLE I
PROPORTION (%) OF EROSION HAZARD CLASSES (A) AND RELATED FACTORS (R, K, L AND S) IN TORRES MUNICIPALITY *

	Qualification and grades of vulnerability to erosion							
Factor	Very low (1)	Low (2)	Mod. low (3)	Mod. (4)	Mod. high (5)	High (6)	Very high (7)	Ext. high (8)
R	<2000 53.7 (4.2)	2000-4000 45.6 (95.8)	4000-6000 0.70	6000-8000	8000-10000	10000-12000	12000-14000	>14000
K	<0.01	0.001-0.005	0.005-0.015 45.3	0.015-0.030 44.6 (74.6)	0.030–0.045 6.6 (10)	0.045-0.060 3.5 (15)	0.060-0.075	>0.075
L	<25 97.5(97.6)	25-50 2.0 (1.9)	50-100 0.5 (0.4)	100-150 (0.09)	150-200 (0.001)	200-250	250-300	>300
S_1	<1 27 (98.6)	1-3 17.9 (1.2)	3-5 9.64(0.1)	5-10 10.6 (0.06)	10-15 8.1(0.04	15-20 7.28	20-25 6.13	>25 13.39
S_2	<3 77.9	3-8 0.8	8 12 1.4	12-20 11.7	20- 30 6.7	30-50 1.5	50-100	>100
D	>250	250-200	200-150	150-100	100-50	50-25	25-10	<10
T	>24	24-20	20-16	16-12	12-8	8-4	4-2	<2
A	<12 72.19	12-25 16.32	25-50 8.48	50-100 2.43	100-150 0.41	150-200 0.1	200-300 0.05	>300 0.02
CPmax	>0.5	0.5-0.12	0.12-0.08	0.08-0.045	0.045-0.018	0.018-0.012	0.012-0.001	<0.001

* According to the classification of Páez (1994) R: rainfall erosivity (MJ·mm·ha^{-1}·h^{-1} per year), K: soil erodability (t·h·MJ^{-1}·mm^{-1}), L: slope length (m), S: slope degree (%), S_2 over 800m, D: effective depth of soil (cm), T: tolerance of soil loss (t·ha^{-1} per year), A: soil erosion hazard (t·ha^{-1} per year), and CPmax: class limit by vulnerability to the erosion (T/R×K×L×S). The proportion in parentheses corresponds to the zone agriculturally developed

TABLE II
PROPORTION (%) OF SUITABILITY DEGREES BY EROSION HAZARD *

	Grades of suitability			
Erosion hazard	Highly suitable	Moderately suitable	Marginally suitable	Not suitable
A (t·ha^{-1} per year)	≤12 72.19 (54.96)	12-25 16.32 (35.16)	25-50 8.48 (9.63)	>50 3.01 (0.25)
CPmax	>0.12 86.54 (100)	0.12-0.045 9.87	0.045-0.012 3.34	≤0.012 0.25

* A according to suitability ratings for rainfed agriculture by FAO (1985) and CPmax according to Páez (1994). The proportion in parentheses corresponds to the agriculturally developed zone.

bute data. The K values were estimated using the soil erodability nomograph method and the combination and average of Eqs. 4, 5 and 6, in the cases of lack of very-fine-sand fraction data in two soil units.

Topographic factors (L and S)

The LS factor was calculated and specially distributed through the command “Spatial Analyst” in ArcGIS.9, applying RUSLE in the grid-based DEM of the study area. The algorithm for computing the S factor was obtained from a DEM-derived surface slope image using the extension Spatial Analyst in ArcGIS.9. Eqs. 11, 12 and 13 were adapted for its determination. The L factor was conditioned at the same time by the space distribution of λ and the m exponent. A combination of Eq. 10 and 9 determined the m value. The λ specially distributed was obtained with the program SAGA.2 GIS (System for Automated Geoscientif Analysis, Goettingen). Before manipulation of this file could be performed, conversion to the ArcGIS form was required.

Crop and management (C) factor

This factor was extracted from a land use/land cover map created previously from Landsat-7 ETM+ image (WRS-2, Path 6/ Row 53). The procedure was implemented systematically in several steps of the work, involving: interpretation of bands, for example, band 4 (vegetation, drainage, delimitation water/soil), and bands 1, 2 and 3 (water, bare soil, roads etc); coloured compositions in red, green and blue (321; 432; 453; 743 and 543); and the NDVI (normalized difference vegetation index) method of vegetation indexing to identify regions without vegetation. Finally, the result of this approach was used to carry out the Decision Tree Classifiers method of classification, using a series of binary decisions to distribute pixels into classes. Data from the NDVI, image spectral values and DEM-derived topographic data were used as criteria to perform the classification. The post-classification techniques Clump and Sieve, Combine Classes, and Edit Class Color were applied to improve the result of the Decision Tree Classifier. Due to lack of information to apply Eq. 14, the crop and management factor C corresponding to each crop/vegetation condition were estimated from RUSLE guide tables (Wischmeier and Smith, 1978; Morgan, 1995). These values were used to re-classify the land/cover map in order to obtain the C factor map of the municipality. A field check previously made in order to collect ground true information, and the ample knowledge of the territory, facilitated the interpreting land use/cover and assigning C values (clouds and shadows classes). For cultivations and fallow lands classes, a value of 0.56 was selected, due to the predominance of sugar cane (*Sacharum* spp.) in the area.

Conservation practices (P) factor

Unfortunately, conservation practices are not considered in the cultivated lands of the zone. However, a P factor map was prepared from land use/cover map. The P factor values were based on work by Morgan *et al.* (1999) adapted to USLE.

Soil erosion hazard

Soil erosion hazard was determined by multiplying the respective RUSLE factors interactively, using Eq. 1. Composite maps of actual and potential erosion hazard were generated. The potential erosion hazard

TABLE III
C FACTOR VALUE * AND PERCENT OF LAND AREA FOR EACH LAND USE CLASS

Land use class	Average C factor	% land area
Water and settlement	0.000	1.24
Dense forest	0.003	4.61
Open forest	0.013	20.61
Grassland	0.150	1.24
Scrubs and shrubs	0.200	15.02
Clouds and shadows	0.313	3.95
Prickly xerophilous vegetation	0.450	19.47
Cultivations and fallow lands	0.560	7.90
Bare soil with ephemeral vegetation	0.900	11.40
Bare soil and rocks	1.000	14.56

* Morgan (1995), Wischmeier and Smith (1978).

TABLE IV
PERCENT OF AREA OF EACH LAND USE TYPE OF CONSERVATION PRACTICES (P) *

Land use type	Slope (°)	P Factor	% land area
Agricultural land	0-1	0.60	7.78
	2-5	0.50	2
	6-7	0.60	-
	8-9	0.70	-
	10-11	0.80	-
	12-14	0.90	-
Other land	all	1	90.22

* Based on Morgan (1999).

was calculated on the basis of R, K and LS.

Suitability ratings for soil erosion hazard

The quantitative output of the different factors was classified according to a system developed by Páez (1994) for agricultural soils in Venezuela (Table I), and according to the suitability ratings for soil erosion hazard for rainfed agriculture (FAO, 1985; Table II). Páez' system uses the CPmax of the USLE (factors C and P) as criterion; it assesses the erosion hazard (sheet and rill erosion) in arable lands, classifies the factors related to erosion in agreement to their potential to cause it, and estimates the requirement of conservation practices and their design specifications. Eight classes and their limit values are established according to conservation requirements of the land units due to erosion risk. CPmax (CPmax= T/R×K×L×S) represents the management requirement in the land unit to control erosion, where T is the tolerance of soil loss established by soil depth (D). R, K, L and S are the erosivity, erodability and slope factors, respectively. Conservation practices requirements increase to the extent that the value of CPmax diminishes. To evaluate the resultant loss in productivity of the land affected by water erosion, the use of the CPmax criterion is proposed. A map of CPmax was elaborated and the degrees of aptitude by risks of erosion in function of this quality were established.

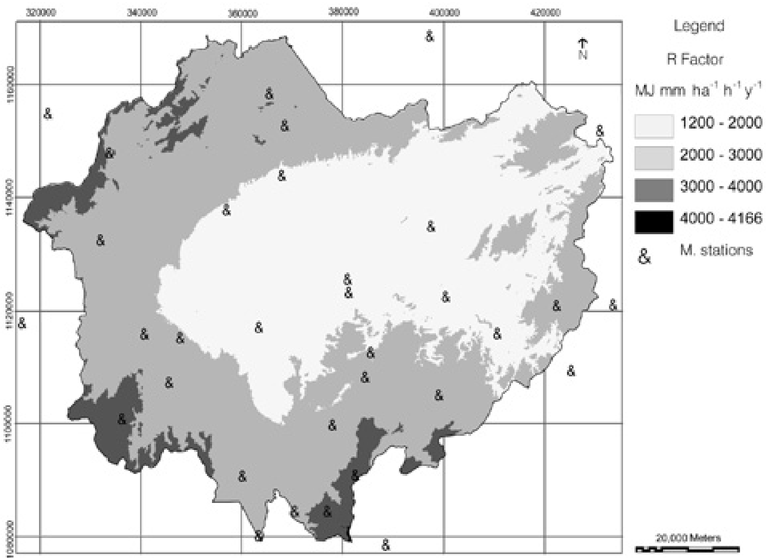

Figure 2. Space distribution of the rainfall-runoff erosivity (R factor).

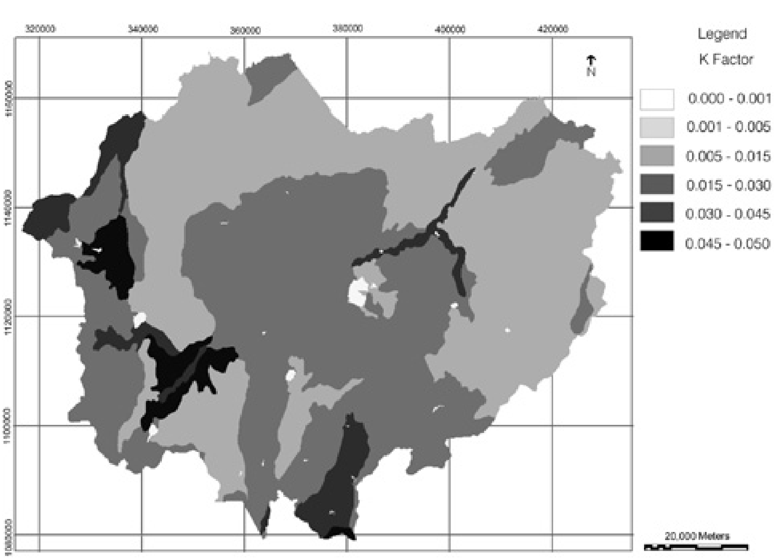

Figure 3. Space distribution of soil erodability (K factor).

Results

RUSLE factors

Tables III and IV, respectively, show the percent of land area for each specified land use class in the map to C and P factors. Figures 2, 3, 4, 5 and 6 show the maps of each factor, where L and S are combined.

Erosion hazard

The potential erosion hazard calculates the soil loss on the basis of climate, soil and topography factors only, i.e. omitting the land use factor. The erosion hazard in t·ha^{-1} per year has a range of 0 to 2558 (very low to moderate) for the actual erosion (Figure 7) and of 0 to 4223 (very low to extremely high) for the potential one (Figure 8). Actual erosion was mainly explained (correlation at P<0.01) by length of slope (L) and cover (C) factors, whereas potential erosion is mainly explained by rainfall-runoff erosivity (R), soil erodability (K), and slope steepness (S) (correlation at P<0.01).

Suitability ratings for soil erosion hazard

Figure 7 shows the actual erosion hazard in the Torres municipality, expressed in four broad classes and ranging from very low hazard areas, where annual soil loss rates average <12 t·ha^{-1} per year (72.19%) to moderate hazard areas with >50t·ha^{-1} per year (3.01%). The proportion (%) tabulated for R, K, L, S, A (actual erosion hazard) and CPmax in each category are presented in Tables I and II, and Figure 9.

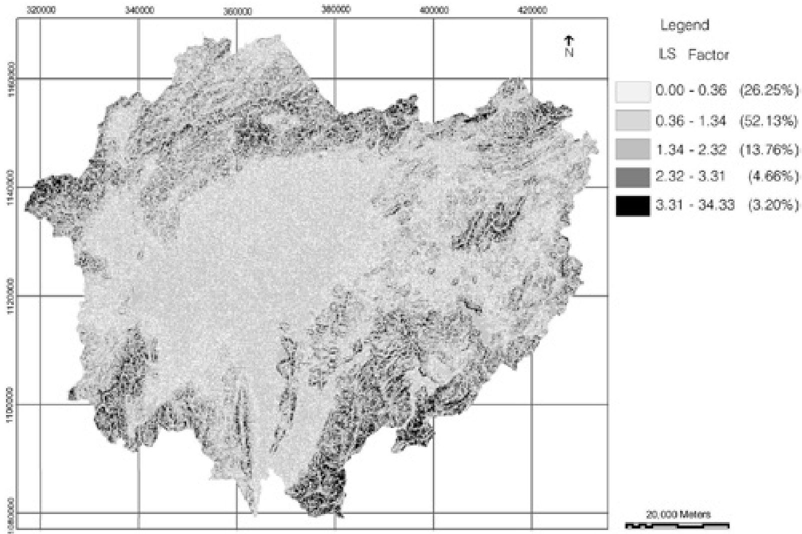

Figure 4. Space distribution of slope steepness and length (LS Factor).

Discussion

RUSLE factors

R values ranged between 1201 and 4166MJ·mm·ha^{-1}·h^{-1} per year (Table I, Figure 2), most of them (53.7% of the study area) within 1201-2000MJ·mm·ha^{-1}·h^{-1} per year. Therefore, rainfall in the area under study has very low potential to cause erosion according to Páez (1994). Ninety-six percent of R values in the agricultural area had low erosivity. The study area, although dry most of the year, is subjected to occasional intensive rains that produce marked erosion (Ferrer, 2003). The calculation of the index of aggressiveness of the rains through the modified Fournier index (MFI) by Arnoldus (1980) indicated that rainfall aggressiveness in the region is moderate to high, and is directly related to elevation, in agreement to Irvem *et al*. (2007). However the present study, in disagreement to Ferrer (2003) and to Fournier index, indicates that R values in the study area have a low erosivity (Andrade, 2007). A cause of this lack of agreement could be the data used to estimate R; the present study used annual and monthly precipitation instead of hourly precipitation, and it does not take into account the hourly-based intensity of the rainfall.

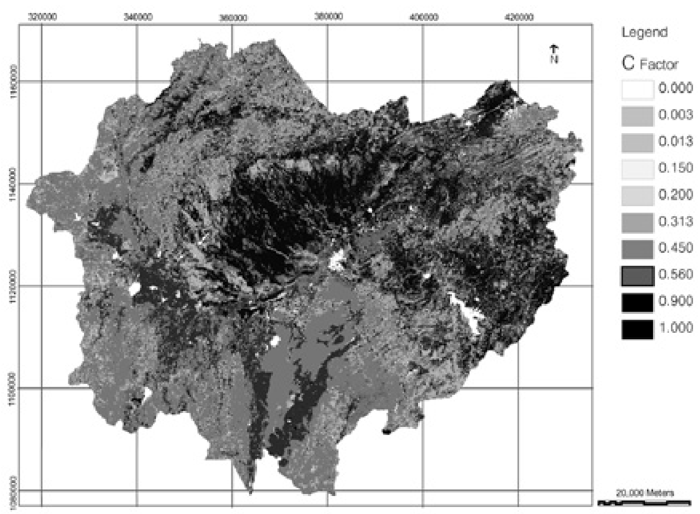

Figure 5. Space distribution of crop and management (C factor).

The soil erodability or K factor (Table I, Figure 3) ranged from moderately low (45.3% of the study area) to high (3.5%), being greater in the cultivated zone or agricultural area. The susceptibility of the study area soils to erosion can be explained by a high content of slime and very-fine-sand fractions (40% and 10%, respectively), which contribute to an easy soil disintegration (Mati *et al*., 2000), although the content of clay reaches 25%. Additionally, the organic matter content is ≤4%. In terms of erosion, soils under these conditions in combination with a hilly topography, poor plant coverage and inappropriate agricultural practices are under serious risk (Irvem *et al*., 2007).

The values of the LS factor are relatively low (Table I, Figure 4); 96.8% of the study area have values <3.31, since most of the area is morphologically flat. The lengths of slopes are <25m (97.6% of the study area). The slope steepness is <3% in 45% of low lands, 80% at high lands and 97.5% in the agricultural soils. This fact suggests that the area topography favors mostly low erosion rates. Steeper and longer slopes are combined in only 3.2% of the area to result in higher runoff velocities and, therefore, greater potential for erosion. Areas of convex topography such as ridges, where flow diverges, had low LS values. A comparison with the slope gradient revealed a clear effect of steepness on the LS factor, with areas of greater slopes having high LS values, and usually corresponding to back slopes between summits and drainage lines (Hoyos, 2005).

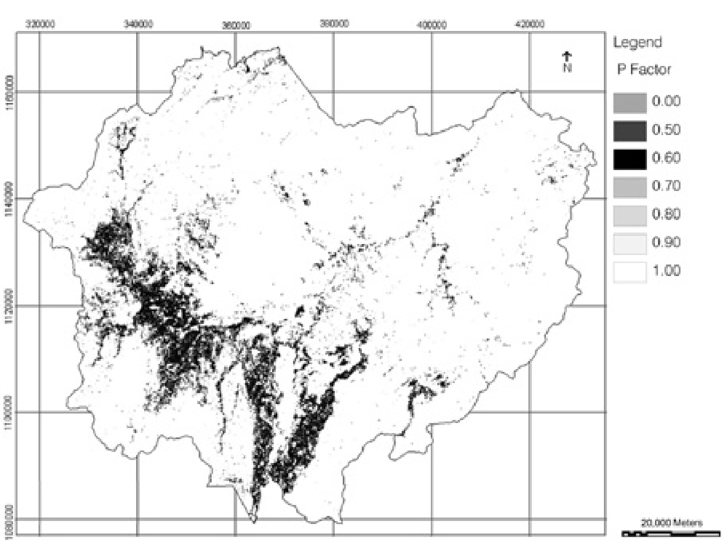

Figure 6. Space distribution of conservation practices (P factor).

Half of the study area possesses two extreme conditions for favoring and avoiding erosion (Table III, Figure 5); bare soil with and without ephemeral vegetation covers 25% of the area, while the forest cover also amounts to 25%. This condition explains the significant correlation of the C factor with the erosion processes.

With respect to the P factor (Table IV, Figure 6), 90.22% of the area has a value of 1, due to the 9.78% of agricultural land. Therefore, the lack of cultures in the area has a large influence on the erosion rates. While the C factor reflects the surface protection effect that dissipates the kinetic energy of raindrops before impacting the surface (Erdogan *et al*., 2006), conservation practices affect erosion mostly by modifying the flow pattern, grade or direction of surface runoff, and by reducing the runoff amount and rate (Renard and Foster, 1983).

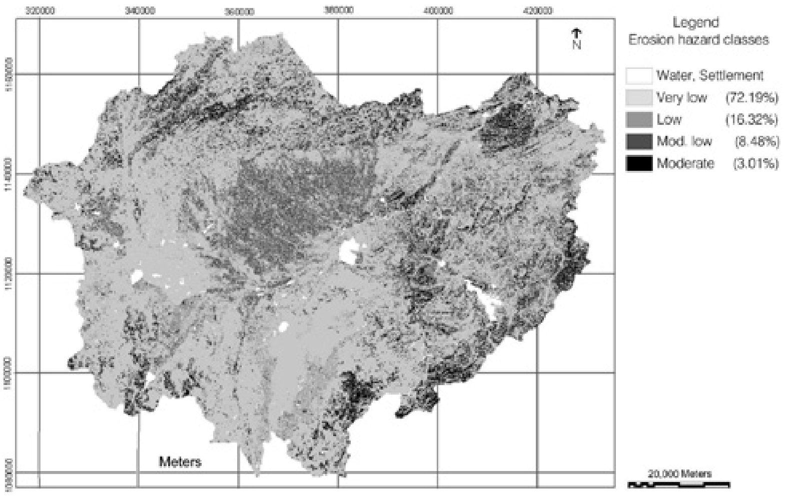

Figure 7. Actual erosion hazard in the Torres municipality.

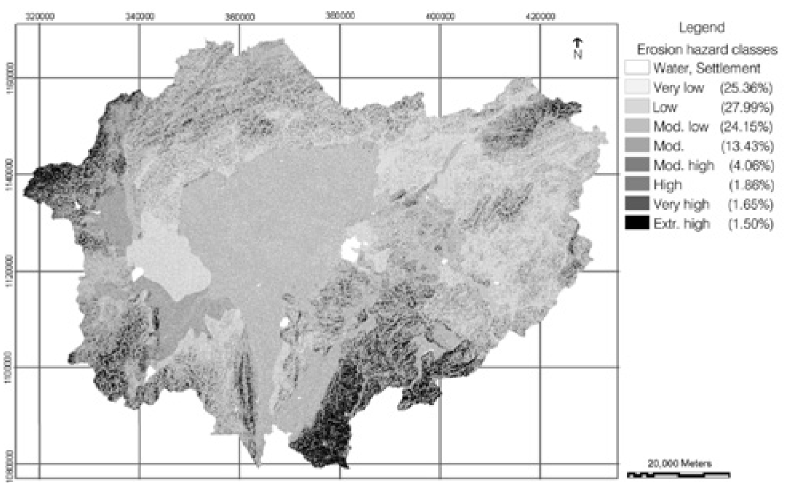

Figure 8. Potential erosion hazard in Torres municipality.

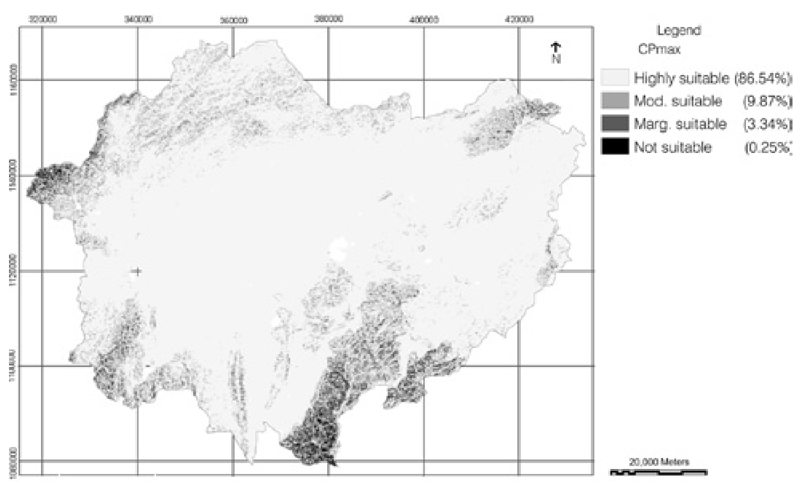

Figure 9. CPmax factor distribution in the Torres municipality.

Soil erosion

Large losses of soil were detected in zones where the following factors are combined: heavy rains (R ≥2000), soils without conservation practices (P= 1) with little vegetal cover (C ≥0.45) and convex topography (LS ≥3.31). Values of these factors are directly related to the losses; the larger are the values the greater the losses (Renard *et al*., 1997). The factors more closely related to the actual erosion were LS and C. It is evident that the areas with the largest soil losses are associated with large values of LS (specially of S), lack of cover and soil erodability. When actual and potential erosion are compared (Figures 7 and 8), the effect of C and P become more evident. Soil losses are duplicated, and moderately high (4.06%), high (1.86%), very high (1.65%) and extremely high (1.5%) erosion, according to Páez' classification (1994) are reached. The protective effect of the vegetation is still greater in the agricultural zone. The sediment yield >25t·ha^{-1} per year could be increased by 100% due to the susceptibility to erosion (moderate to high) of these soils. The lowest erosion values are registered in forest areas (~8% below 8t·ha^{-1} per year) and where agricultural practices are carried out (54.96% <12t), as cultivation reduces considerably the erosive processes, especially in semiarid zones (Oñate, 2004). With respect to areas of natural shrubs, prickly xerophilous and ephemeral vegetation had most of the irreversible soil losses (>50t); when its coverage in the area was considered (15.02, 19.47 and 11.40%, respectively), it appeared that the areas have a serious problem that should be dealt with conservation measures. This is attributed to the fact that the latter type of cover occurred on the slopes with a range of K values of 0.015-0.050. In the agricultural land, soil erosion was not as critical as in these areas, due to the fact that, although they had the relatively higher C values (0.56 *vs* 0.20 and 0.45, respectively), the land used for agricultural crops was located in areas where the range of LS was 0-3.36 and deposition occurred.

Suitability ratings for soil erosion hazard

Table II and Figure 7 show the suitability ratings for soil erosion hazard for rainfed agriculture (FAO, 1985) in all the area. According to this, 72.19% of the area is highly suitable (losses <12t), 16.32% is moderately suitable (losses of 12-25t), 8.48% is marginally suitable (losses of 25-50t) and only 3.01% is not suitable (losses >50t). In the agricultural area, factors R, L and S have very low potential to cause erosion according to Páez (1994), but the K factor is classified as moderate to high. Of the agricultural, 100% is categorized as suitable, because sediment yield does not surpass 50t·ha^{-1} per year, and 54.96% of the agricultural area classifies as highly suitable. The existence of moderate to marginal suitability will call for some combination of land use change, special management practices, or major land improvements (FAO, 1985).

Soil removal as a consequence of erosion causes a decline in agricultural productivity. For example, in Mozambique and Nigeria, a 50% loss in productivity of maize and cowpeas resulted from the removal of 3mm of topsoil from a forest soil with a total depth of 15cm (Saroisong *et al*., 2006). Productivity loss due to erosion is most significant in areas where nutrients concentrate close to the surface, soils with little depth, and areas with high rates of soil loss (FAO, 1985). Considering the soil loss tolerance established by soil depth (>100cm), the percent of high sustainability is 100% in the agricultural area (Table VI, Figure 9), due a CP-max >0.12 (Table II). Based on the conditions reported in the present study, and based on Páez (1994), the zone can be used continuously with annual cultures, mechanized and without conservation practices. Nevertheless, it is desirable to use conservation practices such as vegetative barriers or buffer strip, crop rotation, cover cultivations, green manures, etc.

Conclusions

RUSLE/GIS technology was used to predict soil erosion hazard in the Torres municipality, in the Tocuyo River Basin, Venezuela. Based on the results, the suitability ratings and the requirements for conservation practices were determined. The use, cover, and conservation practices have a decisive influence in the control of the erosive processes. The smallest erosion values of soil losses are registered in zones of forest and where agricultural practices are carried out. Areas susceptible to erosion with a soil loss >12t·ha^{-1} per year are found primarily in the higher basin or where there is little cover. In this area, priority must be given to forest protection and reforestation of steep bare lands. With respect to the assessment of productivity loss due to erosion in the agricultural area, the percentage of high sustainability is 100% in the agricultural area. In accordance with this, the zone can be used continuously with annual cultivations mechanized without conservation practices. Nevertheless, some conservation measures are recommended.

RUSLE is a powerful model for the qualitative as well as for the quantitative assessment of soil erosion intensity for conservation management. However, future work is necessary to validate and confirm the results of RUSLE prediction. GIS is a very useful environment to undertake the task of data compilation and analysis.

ACKNOWLEDMENTS

The authors thank Josué Briceño, Fundación para el Desarrollo de la Región Centroccidental de Venezuela (FUDECO) and Jorge Luis Unda, Ministerio del Poder Popular para el Ambiente (MPPA) for their collaboration to carry out the present study.

REFERENCES

Andrade O (2007) *Generating Information for Land Evaluation in Tocuyo River Basin (Venezuela) by Means of GIS and Remote Sensing: Environmental Parameters, Land Cover, and Erosion Hazard*. Thesis. Georg-August-Universität Göttingen. Germany. 75 pp

Arnoldus H (1980) An approximation of the rainfall factor in the Universal Soil Loss Equation. In De Boodt M, Gabriels D (Eds) *Assessment of Erosion*. Wiley. Chichester, UK. pp. 127-132.

ASCE Task Committee (1970) *Sediment sources and sediment yields. ASCE, J. Hydr. Div. 96* (HY6): 1283-1329.

Barrios A (2002) Distribución espacial del factor LS (RUSLE) usando procedimientos SIG compatibles con IDRISI aplicación en una Microcuenca andina. *Rev. Forest. Venez. 44*: 57-64.

Desmet P, Govers G (1996) A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. *J. Soil Water Cons. 51*: 427-433.

Díaz O (1995) *Estudio de Fragilidad de Suelos y Aplicación de la USLE en Base a SIG para la "Microcuenca El Maqui, Sexta Region, Chile*. Pontificia Universidad de Chile. 81 pp.

Erdogan E, Erpul G, Bayramin I (2006) Use of USLE/GIS methodology for predicting soil loss in a semiarid agricultural watershed. *Env. Monit. Assess. 131*: 153-161.

ESRI (2005) *ArcGIS 9*. Environmental System Research Institute. Redlands, CA, USA.

FAO (1985) *Guidelines: Land Evaluation for Irrigated Agriculture*. Soils Bulletin 55. FAO. Rome, Italy. 123 pp.

Fernández C, Wu J, McCool D, Stockle C (2003) Estimating water erosion and sediment yield with GIS, RUSLE, and SEDD. *J. Soil Water Cons. 58*: 128-136.

Ferrer E (2003) *Analisis Estructural Preliminar de la Hoya del Rio Tocuyo*. 1ª parte. CICHRT. Lara, Venezuela. 12 pp.

Foster G, Meyer L, Onstand C (1997) A runoff erosivity factor and variable slope length exponents for soil loss estimates. *Trans. Am. Soc. Agric. Eng. 20*: 683-687.

Fu G, Chen S, McCool D (2006) Modeling the Impacts of no-till practice on soil erosion and sediment yield with RUSLE, Sedd, and Arcview Gis. *Soil Till. Res. 85*: 38-49.

Hoyos N (2005) Spatial modeling of soil erosion potential in a tropical watershed of the colombian Andes. *Catena 63*: 85-108.

Irvem A, Topaloglu F, Uygur V (2007) Estimating spatial distribution of soil loss over Seyhan river basin in Turkey. *J. Hydrol. 336*: 30-37.

Laflen J, Franti T, Watson D (1985) Effect of tillage systems on concentrated flow erosion. *Proc. Fourth Int. Conf. on Soil Conservation*. Maracay, Venezuela. pp 798-809.

MARN (1993) *Estudios de Suelos de las Sierras de Matatere, Bobare, Trujillo, Barbacoas, Portuguesa, Baragua y Buena Vista*. Escala 1:250.000. Ministerio del Ambiente y los Recursos Naturales. Caracas, Venezuela. 169 pp.

Mati B, Morgan R, Gichuk F, Quintor J, Brewer T, Liniger H (2000) Assessment of erosion hazard with the USLE and GIS: a case study of the Upper Ewaso Ng'iro North basin of Kenya. *Int. J. Appl. Earth Obs. Geoinf. 2*: 78-86.

McCool D, Brown L, Foster G, Mutchler C, Meyer L (1987) Revised slope steepness factor for the Universal Soil Loss Equation. *Trans. Am. Soc. Agric. Eng. 30*: 1387-1396.

McCool D, Brown L, Foster G, Mutchler C, Meyer L (1989) Revised slope steepness factor for the Universal Soil Loss Equation. *Trans. Am. Soc. Agric. Eng. 30*: 1571-1576.

Morgan R (1995) *Soil Erosion and Conservation*. Addison-Wesley. Edinburgh, UK. 198 pp.

Morgan R, Quinton J, Smith R, Govers G, Poesen J, Auerswald K, Chisci G, Torri D, Styczen M (1999) Reply to discussion on the European Soil Erosion Model (Eurosem): a dynamic approach for predicting sediment transport from fields and small catchments. *Earth Surf. Proc. Landform. 24*: 567-568.

Mutchler C, Murphree C, Mcgregor K (1982) Subfactor method for computing C-factors for continuous cotton. *Trans. Am. Soc. Agric. Eng. 25*: 327-332.

Novotny V, Chesters G (1989) Delivery of sediment and pollutants from nonpoint sources: a water quality perspective. *J. Soil Water Cons. 44*: 568-576.

Oñate F (2004) Metodología para la evalución del riesgo de erosión en zonas áridas y su aplicación en el manejo y protección de projectos hidráulicos. Rev. Electr. Redlach. 1:1 6.

Páez M (1994) Clasificación de suelos por riesgo de erosión hídrica con fines de planificación agrícola. *Rev. Fac. Agron.* (Maracay) *20*: 83-100.

Paredes J, Silva O (2004) Evaluación del componente de la erosividad de las lluvias del modelo EPIC en algunas localidades de Venezuela. XVI Cong. Latinoam. Ciencia del Suelo (26/09-01/10/2004) Cartagena de Indias, Colombia. pp. 229.

Poesen J (1992) Mechanisms of overland flow generation and sediment production on loamy and sandy soils with and without rock fragments. In Parsons, AJ, Abrahams, AD (Eds.) *Overland Flow Hydraulics and Erosion Mechanics*. UCL Press, London, Uk. pp. 275-305.

Renard K, Foster G (1983) Soil conservation: principles of erosion by water. In Dregne H, Willis W (Eds.) *Dryland Agriculture*. Agronomy Monograph Nº 23. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America. Madison, WI, USA. pp. 155-176.

Renard K, Foster G, Weesies G, McCool D, Yoder D (1997) *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation* (*RUSLE*). Agric. Handb. No.703. USDA, Washington, DC, USA. 385 pp.

Saroingsong F, Harashina K, Arifin H, Gandasasmita K, Sakamoto K (2007) Practical application of a land resources information system for agricultural landscapes planning. *Landsc. Urban Plann. 79*: 38-52.

Silva O (1995) Descripción general de algunos modelos de simulación de erosión. *Venesuelos 3*: 30-37.

USDA-ARS-BRS (1997) EPIC Software. www.brc.tamus.edu/epic

Wischmeier W, Johnson C, Cross B (1971) *A soil erodibility nomograph for farmland and construction sites. J. Soil Water Cons. 26*: 189-193.

Wischmeier W, Smith D (1978) *Predicting Rainfall Erosion Losses: A Guide to Conservation Planning.* Agric. Manual 537. USDA. Washington, DC, USA. 58 pp.

EVALUACIÓN DEL RIESGO DE EROSIÓN EN EL MUNICIPIO TORRES DEL ESTADO LARA (VENEZUELA) BASADA EN SIG

Onelia Andrade, Martin Kappas y Stefan Erasmi

RESUMEN

El modelo Ecuación Universal de Pérdidas de Suelo Revisada (RUSLE) fue utilizado para predecir riesgos de erosión en el municipio Torres, Lara, Venezuela. Los valores de erosividad de la lluvia (R) indicaron bajo potencial erosivo. Los suelos tienen moderadamente baja a alta erodabilidad (K), incrementándose en la zona agrícola. Los valores del factor LS son relativamente bajos, pues mayoritariamente el área de estudio es morfológicamente plana. La multiplicación celda por celda de R, K y LS dio el mapa de erosión potencial. Un procedimiento similar, adicionando los factores cultivo (C) y prácticas de conservación (P) fue usado para estimar la erosión actual. Los valores más bajos de pérdidas de suelo fueron registrados en zonas agrícolas y bosques. La erosión real fue de 0-2558t·ha^{-1} por año, más del 72% del área tiene muy bajo riesgo de erosión y es altamente apta para agricultura de secano. Áreas susceptibles de erosión con pérdida de suelo >12t·ha^{-1} por año se encuentran principalmente en las partes más altas de la cuenca o donde la cobertura es poco densa. En las zonas agrícolas, el porcentaje de aptitud para fines agrícolas fue de 100%. De acuerdo con esto, la zona puede ser usada continuamente con cultivos anuales mecanizados, sin prácticas de conservación. Los resultados demuestran que la RUSLE bajo ambiente SIG, complementado con data de un modelo digital de elevación (DEM) y sensores remotos, son herramientas poderosas para evaluaciones cuantitativas y cualitativas de la erosión del suelo en una cuenca hidrográfica.

AVALIAÇÃO DO RISCO DE EROSÃO NO MUNICIPIO TORRES DO ESTADO LARA (VENEZUELA) BASEADA EM SIG

Onelia Andrade, Martin Kappas e Stefan Erasmi

RESUMO

O modelo Equação Universal de Perdas de Solo Revisada (RUSLE) foi utilizado para predizer riscos de erosão no município Torres, estado Lara, Venezuela. Os valores de erosividade da chuva (R) indicaram baixo potencial erosivo. Os solos têm moderadamente de baixa a alta erodibilidade (K), incrementando-se na zona agrícola. Os valores do fator LS são relativamente baixos, pois maioritariamente a área de estudo é morfologicamente plana. A multiplicação célula por célula de R, K e LS mostrou o mapa de erosão potencial. Um procedimento similar, adicionando os fatores cultivo (C) e práticas de conservação (P) foi usado para estimar a erosão real. Os valores mais baixos de perdas de solo foram registrados em zonas agrícolas e bosques. A erosão real foi de 0-2558t·ha^{-1} por ano, mais de 72% da área têm muito baixo risco de erosão e é altamente apta para agricultura de sequeiro. Áreas suscetíveis de erosão com perda de solo >12t·ha^{-1} por ano se encontram principalmente nas partes mais altas da bacia ou onde a cobertura é pouco densa. Nas zonas agrícolas, a porcentagem de aptidão para fins agrícolas foi de 100%. De acordo com isto, a zona pode ser usada continuamente com cultivos anuais mecanizados, sem práticas de conservação. Os resultados demonstram que a RUSLE sob ambiente SIG, complementado com dados de um modelo digital de elevação (DEM) e sensores remotos, são ferramentas poderosas para avaliações quantitativas e qualitativas da erosão do solo em uma bacia hidrográfica.