Rev. FCA UNCUYO. 2012. 44(2): 289-299. ISSN impreso 0370-4661. ISSN (en línea) 1853-8665.

Current and potential water erosion estimation with RUSLE3D in Castellon province (Spain)

Estimación de la erosión hídrica actual y potencial con RUSLE3D en la provincia de Castellón (España)

Martín C. Giménez Suárez

Originales: Recepción: 26/05/2012 - Aceptación: 30/10/2012

ABSTRACT

The purpose of this study was the estimation of current and potential water erosion rates in Castellon Province (Spain) using RUSLE3D (Revised Universal Soil Loss Equation-3D) model with Geographical Information System (GIS) support. RUSLE3D uses a new methodology for topographic factor estimation (LS factor) based on the impact of flow convergence allowing better assessment of sediment distribution detached by water erosion. In RUSLE3D equation, the effect that vegetation cover has on soil erosion rate is reflected by the C factor. Potential erosion indicates soil erosion rate without considering C factor in RUSLE3D equation. The results showed that 57% of estimated current erosion does not exceed 10 t/ha.year (low erosion). In the case of potential erosion rates, 5% of the area of Castellon Province does not exceed 10 t/ha.year but 55% exceed 200 t/ha.year. Based on these results, the current vegetation cover of Castellon Province is adequate but needs to be conserved to avoid an increase in the current soil erosion rates as shown by potential erosion rates.

RESUMEN

El objetivo de este estudio fue la estimación de las tasas de erosión hídrica, actual y potencial, en la Provincia de Castellón (España) utilizando el modelo RUSLE3D (Revised Universal Soil Loss Equation-3D), y el apoyo de Sistemas de Información Geográfica (SIG). RUSLE3D utiliza una nueva metodología para la estimación del factor topográfico (factor LS) basado en el impacto de la convergencia del flujo lo cual permite una mejor evaluación del movimiento de sedimentos. En RUSLE3D, el efecto de la cobertura vegetal sobre la tasa de erosión lo refleja el factor C. La erosión potencial representa la tasa de erosión sin considerar el factor C en RUSLE3D. Los resultados mostraron que el 57% de la erosión actual no supera las 10 t/ha.año (erosión baja). En el caso de la erosión potencial, el 5% del área de la provincia es inferior a 10 t/ha.año, pero un 55% supera las 200 t/ha.año (erosión muy alta). En base a estos resultados, la actual cobertura vegetal de la provincia de Castellón es adecuada, pero tiene que ser conservada y protegida para evitar un aumento en las actuales tasas de erosión, tal como lo indican los valores de erosión potencial.

Keywords

soil erosion • sediments • GIS • slope

Palabras clave

erosión del suelo • sedimentos • SIG • ladera

Hydraulics and Hydrology Laboratory, Forest Engineering Department, ETSI Montes, Technical University of Madrid, Ciudad Universitaria s/n, 28040, Madrid, Spain. martincgs@ingenieros.com

INTRODUCTION

Water erosion is a severe and extended issue affecting all European countries, although with different intensities (22). Erosion is one of the major land degradation classes that can cause irreversible degradation (3). The European Mediterranean countries are particularly prone to erosion, because they are subject to prolonged dry periods, followed by heavy erosive rain falling on steep slopes characterized by fragile soils (22).

The process of soil erosion involves detachment, transport and consequent deposition. Sediment is detached from the soil surface both by raindrop impact and by the shearing force of flowing water. The detached sediment is transported downslope primarily by flowing water, although there is also a small amount of downslope transport by raindrop splash (23).

The Universal Soil Loss Equation, USLE, is the most widely used and accepted empirical soil erosion model for water erosion assessment. It was developed for sheet and rill erosion based on a large set of experimental data from agricultural plots (1, 24). In 1997, the Unites States Department of Agriculture (USDA) introduced the Revised Universal Soil Loss Equation (RUSLE) in the Agriculture Handbook No. 703 (18, 19). USLE was developed for detachment capacity limited erosion in fields with negligible curvature and no deposition, and represents soil loss averaged over time and total area (12, 17).

The use of USLE and its derivatives is limited to the estimation of gross erosion, and lack the capability to compute deposition along hillslopes, depressions, or in channels. Moreover, the fact that erosion can occur only along a flow line without the influence of the water flow itself restricts direct application of the USLE to complex terrain within GIS. This one-dimensional structure means that the equation cannot handle converging and diverging terrain, i e., real 3-D landscapes (12).

With advances in Geographical Information System (GIS), erosion models tended to adopt a more explicit representation of the area on which erosion occurs using spatially distributed parameters, providing outputs showing the spatial variability of the process (6). GIS-based approaches provide one of the few means available for systematically examining the role of spatial variability in soil properties, rock types and numerous other geologic and climatic properties in the evolution of a landscape. The spatially explicit nature of GIS analyses and the GIS emphasis on incorporating real-world data combine to make GIS a powerful tool for building insight into the evolution of complex landscapes and landscape processes (4, 7).

Objective

- The assessment of current and potential water erosion rates in Castellon Province with GIS support.

MATERIALS AND METHODS

Study area

Castellon province is located in the North of Valencia Region, Spain (figure 1), between $^{6}78^{574}$ - $^{8}06^{546}$ East and $^{45}21^{568}$ - $^{43}97^{767}$ North coordinates (European Datum 1950 - 30N). The capital of the province is Castellon de la Plana. The study area is approximately 6,636km^2.

Figure 1. Location of Castellon Province in Valencia Region (Spain).
Figura 1. Ubicación de la Provincia de Castellón dentro de la Comunidad Valenciana (España).

The principal geographic characteristics of the Region are the Ramblas (dry riverbeds or wadis) having water only during the rainy season.

Methods

The Universal Soil Loss Equation (USLE) by Wischmeier & Smith (24), and its current revisions, RUSLE (15, 19) and RUSLE3D (13), have been used all over the world in order to estimate the soil mean annual loss per area unit (T):

$$\mathbf{T = R \cdot K \cdot LS \cdot C \cdot P} \qquad [1]$$

where
R = rainfall erosivity factor
K = soil erodibility factor
L = slope length factor
S = topographic slope factor
P = erosion control practice factor
C = cover-management factor representing the effects of vegetation management (soil covers, soil biomass).

The C value is a ratio comparing the existing surface conditions at a site to the standard conditions (19). Potential water erosion is the soil erosion rate without taking into account the vegetation cover.

Specific effects of topography over the soil erosion are estimated by the one-dimensional factor LS, as the product of the slope length factor, *L*, and the slope steepness factor, *S*. As practised on the field, there is subjectivity in deciding exactly where to delimit boundaries for the subfield units of LS in RUSLE.

The accuracy of where breaks for L and S values in a given farm field are located relies on the experience of the field operator partitioning the field into homogeneous LS units (8).

To minimize human subjectivity in estimation of LS factor, calculations based on digital elevation models (DEM) and GIS procedures have been developed, focused on a grid-cell based evaluation of LS factors in a multi-flow context (2, 10, 11, 13). Based on this concept, RUSLE model is named RUSLE3D (technique used in this study).

RUSLE3D equation factors

Factor LS. Spatial Modeling with RUSLE3D

To incorporate the impact of flow convergence, the hillslope length factor (in USLE and RUSLE) was replaced by upslope contributing area (RUSLE3D) (14).

The modified equation for computation of the *LS* factor in finite difference form in a grid-cell representing a hillslope segment was derived by Desmet & Govers (2). A simpler, continuous form of the equation for computation of the LS factor at a point *r=(x,y)* on a hillslope, is by Mitasova *et al.* (12):

$$LS(r) = (m+1)\left[\frac{A_s(r)}{22{,}13}\right]^m \left[\frac{sen\ b(r)}{sen\ 5{,}143°}\right]^n \qquad [2]$$

where

A_s [m] = specific catchment area and is the upslope contributing area, divided by the contour width which is assumed to equal the width of a grid cell

b [deg] = slope

m and *n* = parameters for a specific prevailing type of flow and soil conditions

22.13 m is the length and 0.09 = 9% = 5.143 deg is the slope of the standard USLE plot (13).

LS factor estimation (9, 12, 13) was supported by GIS software, ArcGIS® 9.3 and GvSIG® (16). The GIS GvSIG offers very significant advantages in terms of the hydrological analysis having several algorithms included to estimate slope inclination and flow accumulation, in comparison with ArcGIS. GvSIG is a free software, available in English and Spanish (http://www.gvsig.gva.es/).

To obtain the map with LS factor values and then integrate it into RUSLE3D, the following steps must be fulfilled:

I. Create a digital elevation model (DEM).
II. Calculate slope inclination map.
III. Calculate flow accumulation map (upslope contribution area).
IV. Calculate specific catchment area map, A_s.

Rainfall erosivity factor, R (hj.m^{-2}.cm.h^{-1})

This factor represents rainfall power to erode soil surface, and is defined as the product of rainfall energy and maximum 30-min intensity.

Given the complexity presented by the calculation of this factor, there are various procedures for its determination, mostly based on regression analysis, where the variables are easily obtainable.

In a report of Roldán (20), a new equation has been made with high correlation coefficients and well-distributed residuals. The most important result of this work was an equation made specifically for Mediterranean climate. The advantage is that it only needs annual precipitation value to calculate the R factor (Eq. 3).

$$Rannual = 0.007 \times Pannual1.577 \quad [3]$$

Figure 2 shows the distribution of the average annual precipitation (mm) for the province of Castellon.

Using GIS support, Equation 3 was applied over the average annual precipitation raster map, in order to estimate R factor values.

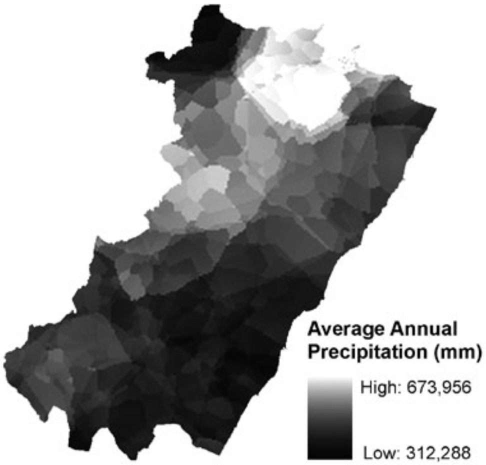

Figure 2. Distribution of the average annual precipitation (mm) for the Province of Castellon.
Figura 2. Distribución de la precipitación media annual (mm) en la provincia de Castellón.

Soil erodibility factor, K ($t.m^2.h/ha.hj.cm$)

The K factor represents both susceptibility of soil to erosion, and the amount and rate of runoff. Soil texture, organic matter, structure, and permeability determine the erodibility of a particular soil (4, 25).

The province is characterized by soil units consisting of Kastanozems, Phaeozems Chernozems generally associated with rendzic and humic leptosols and molihumic Regosols showing equilibrium with vegetation. This leads to a greater and deeper integration of organic matter and a moderate to high structural stability. These soils are associated with areas covered by dense natural vegetation (21).

On the other hand, soils as Calcisols (CL ha, CL pt and CL lv) and Calcaric Regosols are generally related to crop soils in areas with low content of organic matter, where the use and management practices facilitate the destruction of the structure, especially on tilled horizons (21).

K factor is highly correlated with lithology; therefore, for the calculation of this factor, a lithostratigraphic vector layer was used (from Spanish Geological and Mining Institute) and pedological database, courtesy of Valencia Waste Energy Use. The decision to use the lithology instead of data soil, was taken due to the fact that the latter is not available for the whole area of the province

Cover-management factor, C (non-dimensional)

The C factor is used to reflect the effect of the protection offered to the soil surface by the vegetative canopy, and the impacts of cropping and management practices on erosion rates (19). When the effect of vegetation cover (C factor) is not taken into account in RUSLE3D equation, the result is the potential erosion rate. The potential erosion assessment shows the variation of soil erosion rates compared with current erosion rates.

The data for the calculation of this factor was obtained from SIOSE. SIOSE is the Land Occupation Information System of Spain, which aims to integrate information from databases of land-cover and use from the Autonomous Regions of Spain. The SIOSE is part of the Spanish National Plan of Monitoring Territory (PNOT), which coordinates and manages the National Geographic Institute of Spain (IGN) and the National Center for Geographic Information of Spain (CNIG).

SIOSE separates land use in polygons. According to SIOSE, up to eight covers can exist in a same polygon; therefore, the C factor value for each polygon obtained is a mean value, which results from the combination of the different covers inside the polygon.

Erosion control practice factor, P (non-dimensional)

The P factor is the ratio of soil loss with a specific support practice (contouring, strip-cropping, terracing) to the corresponding loss with upslope and downslope tillage.

RESULTS

RUSLE3D Factors

LS factor

Figure 3 shows LS values for the province of Castellon estimated with the equation 2.

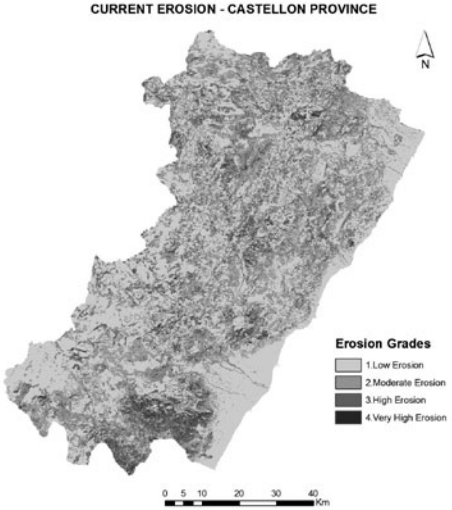

Figure 3. LS values for the province of Castellon.
Figura 3. Valores del factor LS para la provincia de Castellón.

R factor

Figure 4 shows R values of the province of Castellon.

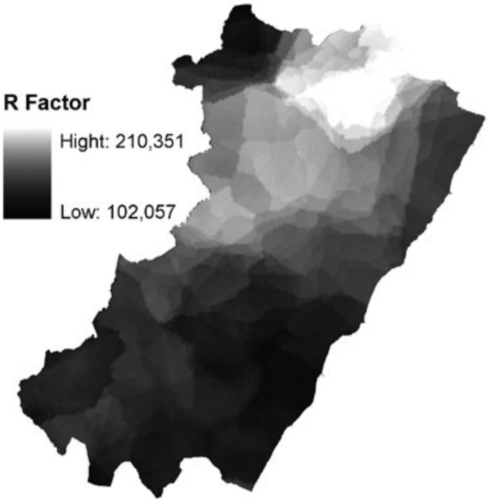

Figure 4. R values of the province of Castellon.
Figura 4. Valores del factor R para la provincia de Castellón.

K factor

Table 1 shows K values for the main lithologic groups in the province of Castellon.

Table 1. K factor values according to the lithology of the province of Castellon.
Tabla 1. Valores del factor K, estimados a partir de la litología, para la provincia de Castellón.

LITHOLOGY	K FACTOR
Sandstone	0.22
Sandstones and Limestone	0.14
Limestone	0.15
Dolomites	0.14
Shale Siliceous	0.24
Marl and Limestone	0.08
Mix Limestone	0.21

C factor

Table 2 shows the values of C factor for the main covers of SIOSE database. A value of zero was given to buildings, water areas and rock outcrops, because these covers do not generate soil erosion. On the other hand, the maximum value for a C factor, 0.45, was given to "land without vegetation" (*e. g.* bare soil).

Table 2. C factor values according to SIOSE coverage database for the province of Castellon.
Tabla 2. Valores del factor C a partir de la base de datos de coberturas del SIOSE para la provincia de Castellón.

COVERAGE	C FACTOR
Woodland Forest (*e. g.* Conifers)	0.01
Artificial Association (*e. g.* Road Network)	0
Artificial Coverage (*e. g.* Pedestrian Zone)	0
Water Coverage (*e. g.* Lakes)	0
Crops (*e. g.* Fruit Trees)	0.4
Scrubland	0.1
pastureland	0.05
Bare Soil	0.45

P factor

In this case, a value of 1 was assigned to P factor, because there is no conservation practice in the study area.

Current water erosion rates

The 57% of the estimated erosion does not exceed 10 t/ ha.year, i.e., approximately 380,000 hectares of the area of the Castellon Province have minimal risk of erosion (table 3, page 297). Another important fact is that 98% of the area of the Province does not exceed 200 t/ha.year, *i. e.*, which is the lowest limit of the classification by FAO-PNUMA-UNESCO (5) for "very high" erosion rates (figure 5, page 297). These results imply that half of the Province does not require conservation treatments but just 2% of the area need urgent treatments.

Table 3. Assessment of current erosion rates calculated with RUSLE3D in t/ha.year in Castellon Province (Spain).

Tabla 3. Evaluación de la actual tasa de erosión en la Provincia de Castellón (España) en t/ha.año, calculada con RUSLE3D.

	RUSLE3D	
Erosion Rates (t/ha.year)	**Area (%)**	**Area (ha)**
Low Erosion (0-10 t/ha.year)	57.3	380334
Moderate Erosion (10-50 t/ha.year)	28.7	190631
High Erosion (50-200 t/ha.year)	12.6	83718
Very High Erosion (>200 t/ha.year)	1.3	8942
Total	100.0	663625

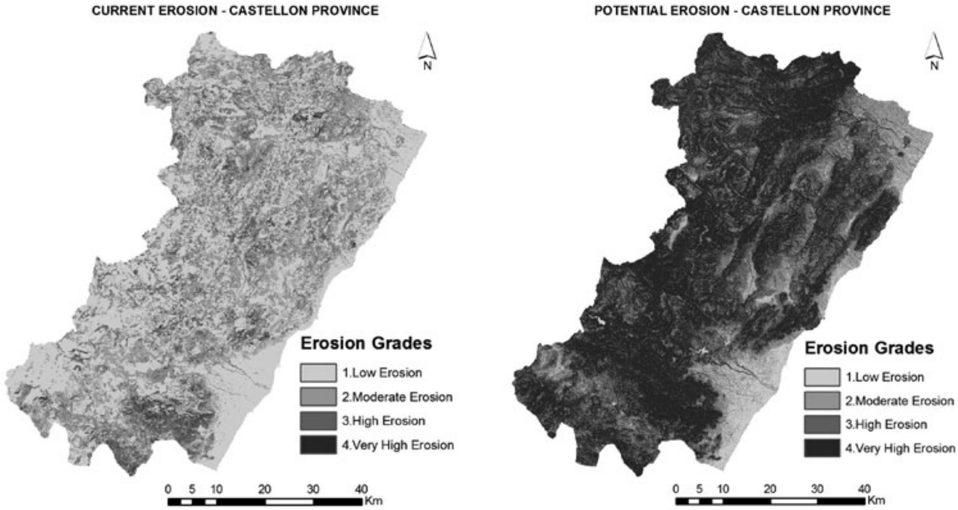

Figure 5. Current and potential erosion maps of Castellon Province (Spain).

Figure 5. Mapas de erosión actual y potencial de la provincia de Castellón (España).

Potential water erosion rates

In this case, results show (table 4, page 298) that, if vegetation cover is not considered, 5% of the area of Castellon Province does not exceed 10 t/ha.year, and 55% exceed 200 t/ha.year, *i. e.*, the highest level of risk of erosion (figure 5). These results significantly demonstrate the importance of vegetation cover with regard to protection of soil.

Tabla 4. Evaluación de la tasa de erosión potencial en la Provincia de Castellón (España) en t / ha.año, calculada con RUSLE3D.
Table 4. Assessment of potential erosion rates calculated with RUSLE3D in t / ha.year in Castellon Province.

	RUSLE3D	
Erosion Rates (t/ha.year)	**Area (%)**	**Area (ha)**
Low Erosion (0-10 t/ha.year)	4.9	32468
Moderate Erosion (10-50 t/ha.year)	11.9	78692
High Erosion (50-200 t/ha.year)	28.0	186114
Very High Erosion (>200 t/ha.year)	55.2	366351
Total	100,0	663625

CONCLUSIONS

- Determination of soil erosion should be the first element to be considered in planning. Erosion models, such as RUSLE3D, predict erosion patterns over an area of study that can be useful as a basis or guide for future land conservation practices.

- RUSLE3D equation allows a more accurate estimation of the distribution of sediment removed by water erosion effects, and how the vegetation cover affects its assessment.

- All the parameters included in the RUSLE3D equation are important but the results show that the absence of vegetation would generate a considerable increase in erosion rates. According to this, we concluded that the present vegetation cover of Castellon Province is adequate, and has to be protected and conserved in order to avoid the increase of soil erosion rates.

REFERENCES

1. Delgado, M. 2010. Modelización de la pérdida de suelo en sierras del Sudoeste de la Provincia de Buenos Aires. Revista de la Facultad de Ciencias Agrarias de la Universidad Nacional de Cuyo. Mendoza. Argentina. 42(2): 1-14.
2. Desmet, P.; Govers, G. 1996. A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. Journal of soil and water conservation. 51: 427-433.
3. Dregne, H. E. 2002. Land degradation in the drylands. Arid Land Research and Management. 16: 99-132.
4. Efe, R.; Ekinci, D.; Cürebal I. 2008. Erosion analysis of Findikli creek catchment (NW of Turkey) using GIS based on RUSLE (3D) method. Fresenius Environmental Bulletin. 17: 568-576.
5. FAO-PNUMA-UNESCO. 1980. Metodología provisional para la evaluación de la degradación de los suelos. Organización de las Naciones Unidas para el Desarrollo de la Agricultura y la Alimentación (FAO), Programa de las Naciones Unidas para el Medio Ambiente (PNUMA), Organización de las Naciones para el Medio Ambiente (UNESCO). Roma, Italia. (In Spanish).
6. Feng, X.; Wang, Y.; Chen, L.; Fu, B.; Bai, G. 2010. Modeling soil erosion and its response to land-use change in hilly catchments of the Chinese Loess Plateau. Geomorphology. 118: 239-248.
7. Finlayson, D.; Montgomery, D. 2003. Modeling large-scale fluvial erosion in geographic information systems. Geomorphology. 53: 147-164.
8. García, J. L.; Giménez, M. C. 2010. Estimation of slope length value of RUSLE factor L using GIS.

J. Hydrologic Engineering. 15: 714-717.
9. García, J. L.; Giménez, M. C. 2012. Methodology for estimating the topographic factor LS of RUSLE3D and USPED using GIS. Geomorphology. 175-176: 98-106.
10. Giménez, M. 2008. Metodología de cálculo del factor topográfico, LS, integrado en los modelos RUSLE y USPED. Aplicación al Arroyo del Lugar, Guadalajara (España). Ph. D Thesis. ETSI Montes. Universidad Politécnica de Madrid. UPM Digital Library. Disponible en: http://oa.upm.es/1914/ (Fecha de consulta: 25 de marzo de 2012).
11. Lewis, L. A.; Verstraeten, G.; Zhu, H. 2005. RUSLE applied in a GIS framework: Calculating the LS factor and deriving homogeneous patches for estimating soil loss. International Journal of Geographical Information Science. 19: 809-829.
12. Mitasova, H.; Brown, W. M.; Johnston, D.; Mitas, L. 1996. GIS tools for erosion/deposition modeling and multidimensional visualization. PART II: Unit Stream Power-Based Erosion/Deposition Modeling and Enhanced Dynamic Visualization. Report for USA CERL. University of Illinois. Urbana-Champaign, IL. 38 p.
13. Mitasova, H.; Mitas, L. 1999. Modeling soil detachment with RUSLE3D using GIS. University of Illinois at Urbana-Champaign. Disponible en: http://skagit.meas.ncsu.edu/~helena/gmslab/erosion/usle.html (Fecha de consulta: 20 de julio de 2011).
14. Moore, I.; Burch, G. 1986. Physical basis of the length-slope factor in the Universal Soil Loss Equation. Soil Science Society of America Journal. 50: 1294-1298.
15. Moore, I. D.; Wilson J. P. 1992. Length-slope factors for the Revised Universal Soil Loss Equation: Simplified method of estimation. Journal of Soil and Water Conservation. 47: 423-428.
16. Olaya, V. 2006. Fundamentos de Análisis Geográfico con SEXTANTE. Edición 1.0. UNEX. Extremadura. Spain. 355 p. (In Spanish).
17. Panagopoulos, T.; Antunes, M. D. 2008. Integrating Geostatistics and GIS for Assessment of Erosion Risk on Low Density Quercus suber Woodlands of South Portugal. Arid Land Research and Management 22: 159-177.
18. Renard, K. G.; Foster, G. R.; Weesies G. A.; Porter J. P. 1991. RUSLE: Revised Universal Soil Loss Equation. J. Soil Water Conserv. 46: 30-33.
19. Renard, K. G.; Foster, G. R.; Weesies, G. A.; McCool, D. K.; Yoder, D. C. 1997. Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE). Agriculture Handbook N° 703. U.S. Department of Agriculture, Agricultural Research Service. Washington, Columbia. 404 p.
20. Roldán, M. 2006. El Poder de la Lluvia. Características de la precipitación y erosividad. Nueva formulación para la estimación de la erosividad. Aplicación al cálculo del factor R de la USLE. Ministerio de Medio Ambiente. España. (In Spanish).
21. Sánchez Díaz, J.; Valera Lozano, A.; Carbó Valverde, E. 2011. El factor K en los suelos de la comunidad valenciana, comparación a nivel espacial en la provincia de Castellon. Control de la degradación y uso sostenible del suelo. Libro de Actas del V Simposio Nacional sobre Control de la Degradación y Uso Sostenible del Suelo: 251-254.
22. Terranova, O.; Antronico, L.; Coscarelli, R.; Iaquinta, P. 2009. Soil erosion risk scenarios in the Mediterranean environment using RUSLE and GIS: An application model for Calabria (Southern Italy). Geomorphology 112: 228-245.
23. Walling, D. 1988. Erosion and sediment yield research-some recent perspectives. J. Hydrol. 100: 113-141.
24. Wischmeier, W. H.; Smith, D. D. 1978. Predicting rainfall erosion losses. A guide to conservation planning. USDA Agric. Handbook n° 537. 58 p.
25. Yýlmaz, M.; Yýlmaz, F.; Karagul, R.; Altun, L. 2008. Changes in erodibility indices and some soil properties according to parent materials and land use regimes in erfelek dam creek watershed (Sinop, Turkey). Fresenius Environmental Bulletin 17: 49-58.