Int. J. Environ. Res., 8(1):61-68,Winter 2014
ISSN: 1735-6865

Water and Wind Erosion Risk in Natural Parks –A Case Study in "Las Batuecas–Sierra de Francia" and "Quilamas" Protected Parks (Central System, Spain)

Martínez-Graña, A. M.[1*] Goy, J. L.[1] and Zazo, C.[2]

[1] Geology Department, External Geodynamics Area, Science Faculty, University of Salamanca, Plaza Merced s/n, (37008), Salamanca, Spain

[2] National Museum of Natural Sciences, Section Geology, Street José Gutiérrez Abascal No. 2. (28006), Madrid, Spain

Received 11 Feb. 2013; Revised 28 May 2013; Accepted 17 June 2013

ABSTRACT: This paper presents a mapping procedure for risk mapping of water and wind erosion, which helps to identify protective measures needed in the planning and management of natural parks. The map of water erosion risk was developed by combining the original and revised universal soil loss equation methodologies (USLE-RUSLE), and the map of wind erosion risk was developed using Quirantes' method. Using GIS techniques allows parametric characterisation of the factors involved in the processes of soil degradation. The validation procedure was carried out in two natural parks in the Spanish Central System. Integration of the two maps resulted in a risk map of water and wind erosion. This mapping shows a high risk of water erosion in areas of high slopes and elevations with little agricultural activity and undulating reliefs. The risk of wind erosion is lower in sectors with analytical and textural high erodibility and low vegetation cover.

Key words: Water and wind erosion, Risk mapping, GIS, Environmental planning, Natural parks

INTRODUCTION

The risks involved in the planning process in Spain are beginning to be considered under Law 9/2006, which assesses the effects of certain plans and programs on the environment, replacing Directive 2001/42/CE. Previously, natural hazards, and in particular the risks of erosion, were not taken into account, resulting in huge material and economic losses. Correct quantification of the volume of material lost using erosion risk mapping assists with making decisions concerning the adoption of preventive and protective measures (terracing, farming practices, etc.) to halt desertification in central and southern Spain. The United Nations Conference on Desertification, held in 1977 in Nairobi, Kenya, identified the need for further study of the risks of erosion, which precedes desertification. Thus, in 1978, the former National Institute for the Conservation of Nature (ICONA) analysed the erosion problems in Spain and identified the more influential degradation processes as wind erosion, salinisation and physical and biological degradation. In 1979, the problem of national water erosion was systematically analysed, along with erosion damage in relation to the rain or erosivity factor R. In 1980, the Global Strategy for the Conservation of Nature was established in Madrid and sponsored by the World Conservation Union (IUCN), the United Nations Environment Programme (UNEP) and the World Wildlife Foundation (WWF), in collaboration with FAO and UNESCO. Soil was identified as a vital system because its existence directly determines the quality of food production. In Spain, there are 21 million ha of arable land, and this area is considered to be reduced by one quarter due to fallow situations, which means that an existing soil deficit of 0.45 ha/capita exists, if we consider a population of 47 million. Erosion, desertification and population growth worsen this situation.

In 1982, ICONA studied the different factors that influence the USLE-RUSLE, initially in the Mediterranean region of Spain and later in the rest of the country, and developed United erosion maps at a scale of 1/400 000 by watershed, with the first maps published in 1987. To enhance the Nairobi Plan and regional cooperation, ICONA developed a project called Combat Desertification in the Mediterranean (LUCDEME). In 1985, Law 29/1985 reinforced the study of water erosion and established the guidelines for including water plans in erosion research in article 40. In 1995, as part of the project LUCDEME, a network of

---

*Corresponding author E-mail:amgranna@usal.es experimental stations for the monitoring and evaluation of erosion and desertification was created, and in 1996, Spain ratified the United Nations Convention to Combat Desertification and developed a National Action Program to Combat Desertification. In 2000, by Royal Decree 1415, the Ministry of the Environment, assigned to the Directorate General of Nature Conservation, updated the National Inventory of Soil Erosion and corresponding erosion State Maps, gathering all these documents into the so-called Nature Data Bank. In 2001, a national plan for priority actions on hydrologic–forest restoration, erosion control and defence against desertification was established.

The evaluation of wind erosion is more recent, having first begun in the 1970s with assessments of actual and potential erosion. Wind erosion can be measured directly in the field, using instruments that evaluate the erosion rate by analysing wind-borne particles, or in wind tunnels, where a constant and measurable stream of air can be applied. Evaluation of erosion potential involves predicting soil loss due to wind action, including identifying the most erodible soils. In Spain, this area of research has evolved considerably, including the development of the semiquantitative methods applied in this study (Quirantes Puertas, 1991) on the basis of field and laboratory parameters.

In 2002, the maps of erosion states that had been developed earlier were thoroughly reviewed and updated, with scales applicable to environmental planning studies, in accordance with Directive 2001/42/CE. The first National Inventory of Soil Erosion (2002-2012) was developed, with degrees of desertification being determined using GIS and remote sensing techniques. (Cantón *et al*., 2011). Having established the importance of risk assessment studies as indicators of erosion in the degradation of natural areas, to prevent environmental, social and economic losses. These indicators explain the efforts of various international organisations (FAO, USDA, EU, etc.) to develop methodologies to accurately estimate current and future soil loss. In the region of Castilla y León, the inventory of soil erosion is still unfinished, but it is still very important to analyse the risks of erosion due to progressive depopulation linked to the decline in farm profitability, especially in natural areas.

The objective of this work was to establish soil loss rates due to erosion by water and wind in protected natural areas, to predict the environmental effects of different land uses and avoid major disasters that in some cases are irreversible. With respect to the risk of water erosion, analysis mapping, involving calculating the potential and actual erosion leading to loss of soil resources, can help in the selection of protective and corrective techniques (crop selection, reforestation, infrastructure, etc.). The risk of wind erosion is mapped by a procedure similar to that for water erosion and makes it possible to identify and characterise the main areas of wind erosion by diagnosing the risk of degradation by wind.

The focus of this study was the protected natural areas Las Batuecas–Sierra de Francia and Quilamas (Fig. 1), where afforestation is highly mechanised, involving soil disturbance (using "rippers") that increase erosion due to the movement of machinery that breaks up the soil into easily draggable fragments, especially on steep slopes with low soil strength, and/or thin substrates. Environmental impact studies are needed in such areas before recommendations can be made concerning reforestation, conservation and sustainable soil practices. Manual dibbling, although more expensive than mechanised afforestation, affects slope stability and consequent soil loss to a lesser extent.

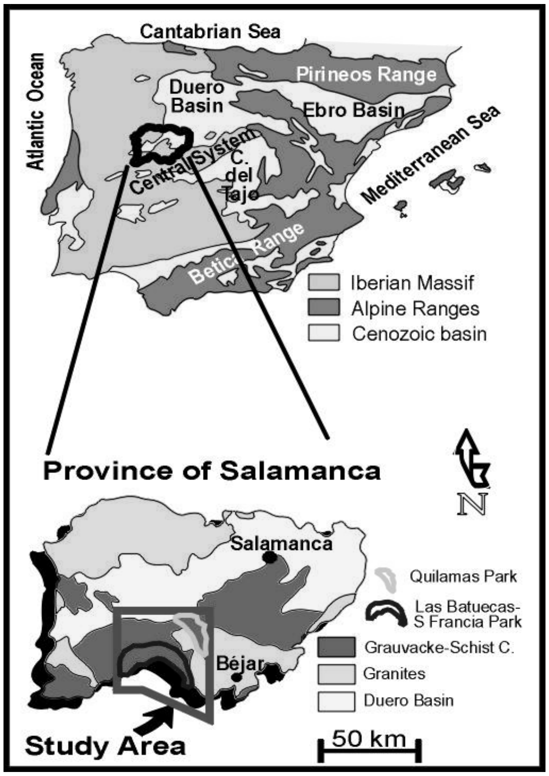


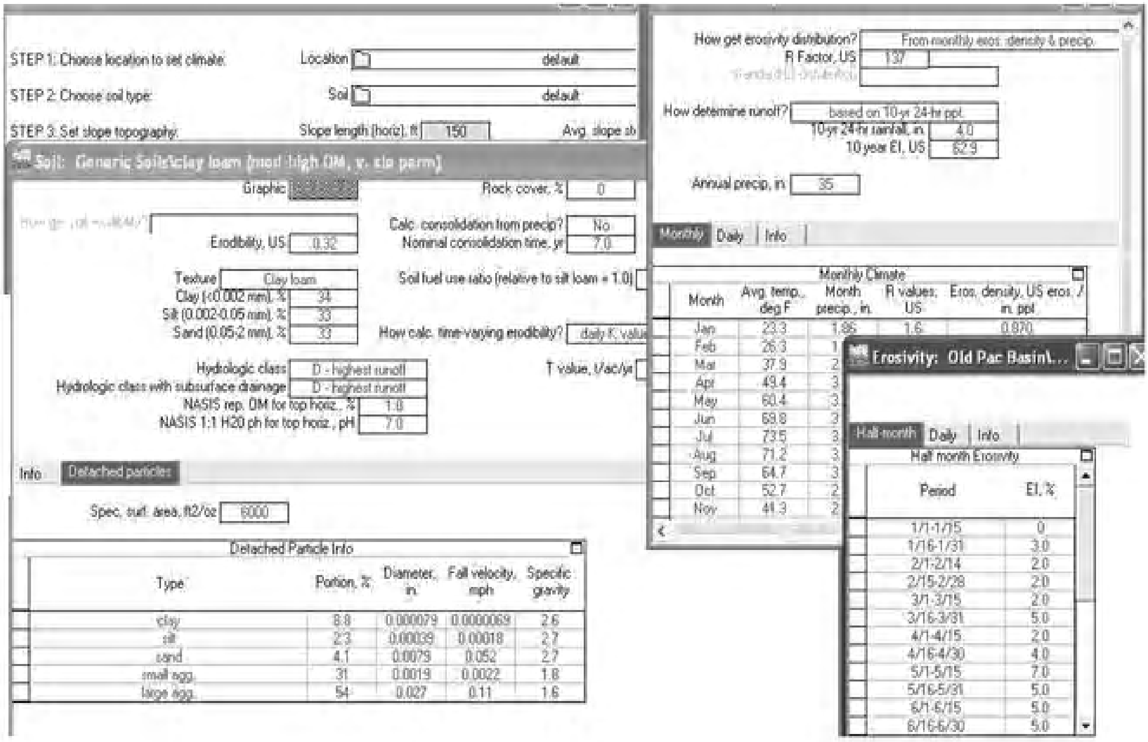
Fig. 1. Study Area

In the area of Las Batuecas–S. de Francia and Quilamas, water erosion is dominant and shapes the landscape in areas of very high elevation. A conservationist stance prevails toward controlling erosion by reducing the rate of soil loss to tolerable levels, i.e., quantitatively reducing the volume of soil lost through the quantitative and qualitative analysis and evaluation of environmental land degradation regarding the loss of organic matter and nutrients. This new approach considers not only runoff control measures but also protection of the soil cover.

MATERIALS & METHODS

The risk map analysis of water and wind erosion was performed using GIS techniques (López and Navas, 2010) because of its usefulness in management and computation in environmental analysis and its applicability to the use and implementation of georeferenced databases, which enables the management of thematic layers of information in open systems, integrates different factors of the natural environment and provides cartographic simulation models. The database generated for the Natural Parks Las Batuecas–Sierra de Francia" and "Quilamas is a useful tool in spatial planning and management of land use that can be used to improve the management of human activities in areas of high erosion incidence.The calculation of soil loss by water and wind erosion was conducted by indirect empirical evaluation. The water erosion model used was USLE (the Universal Soil Loss Equation) and RUSLE.v2 (the Revised Universal Soil Loss Equation). The wind erosion model used was that of Quirantes. The USLE model, by its simple parametric structure and its improvement in the form of RUSLE, examines the correlation and interaction among factors such as the rainfall erosivity R-factor (climatic aggressiveness), the erodibility K factor (representing the soil and lithological characteristics of the substrate), the topographical factor LS (representing the slope and the length of the slope), the ground cover factor C and the conservation practices factor P. USLE and RUSLE.v2 (Fig. 2) are the erosion prediction models most widely used in the development of soil conservation policies. (Bou Kheir, 2008; De Luis, *et al*., 2010).The calculation of the risk of water erosion was conducted by combining USLE (Wischmeier and Smith, 1978) with RUSLE v.2, adapting the quantification of the parameters for our study area. The method for calculation of water erosion (Fig. 3) involves first calculating the R factor representing rain or the aggressiveness of erosive rainfall recorded at 20 weather stations in the sector with at least 20 years of continuous rainfall records. The index used was the modified Fournier index Fm (Arnoldus, 1980) because this index best represented the combination of the volume and concentration of rain, considering the dispersion of the rainfall stations and the distribution of rainfall with the topography. A mapping "grid" of spatial distribution was generated by the inverse distance weighted method (IDW).

The mapping erodibility or K factor, which reflects the susceptibility or vulnerability to soil erosion, was


STEP 1: Choose location to set climate: Location: default
STEP 2: Choose soil type: Soil: default
STEP 3: Set slope topography: Slope length (horiz), ft: 150
Avg. slope st

Soil: Generic Soils\clay loam (mod high OM, v. slo perm)

Graphic
Rock cover, %: 0
Erodibility, US: 0.32
Calc. consolidation from precip?: No
Nominal consolidation time, yr: 7.0
Texture: Clay loam
Clay (<0.002 mm), %: 34
Silt (0.002-0.05 mm), %: 33
Sand (0.05-2 mm), %: 33
Soil fuel use ratio (relative to silt loam = 1.0)
How calc. time-varying erodibility?: daily K valu
Hydrologic class: D - highest runoff
Hydrologic class with subsurface drainage: D - highest runoff
T value, t/ac/yr
NASIS rep. OM for top horiz., %: 1.0
NASIS 1:1 H20 ph for top horiz., pH: 7.0
Spec. surf. area, ft2/oz: 6000

Detached Particle Info

Type	Portion, %	Diameter, in	Fall velocity, mph	Specific gravity
clay	8.8	0.000079	0.0000069	2.6
silt	2.3	0.00039	0.00018	2.7
sand	4.1	0.0079	0.052	2.7
small agg.	31	0.0019	0.0022	1.8
large agg.	54	0.027	0.11	1.6

How get erosivity distribution?: From monthly eros. density & precip.
R Factor, US: 137
How determine runoff?: based on 10-yr 24-hr ppt.
10-yr 24-hr rainfall, in: 4.0
10 year EI, US: 62.9
Annual precip, in: 35

Monthly Climate

Month	Avg. temp., deg F	Month precip., in	R values, US	Eros. density, US eros. / in. ppt
Jan	23.3	1.86	1.6	0.870
Feb	26.3	1		
Mar	37.9	2		
Apr	49.4	3		
May	60.4	3		
Jun	69.8	3		
Jul	73.5	3		
Aug	71.2	3		
Sep	64.7	3		
Oct	52.7	2		
Nov	41.3	2		

Erosivity: Old Pac Basin\...

Half month Erosivity

Period	EI, %
1/1-1/15	0
1/16-1/31	3.0
2/1-2/14	2.0
2/15-2/28	2.0
3/1-3/15	2.0
3/16-3/31	5.0
4/1-4/15	2.0
4/16-4/30	4.0
5/1-5/15	7.0
5/16-5/31	5.0
6/1-6/15	5.0
6/16-6/30	5.0

Fig. 2. Application RUSLE v.2 K factor

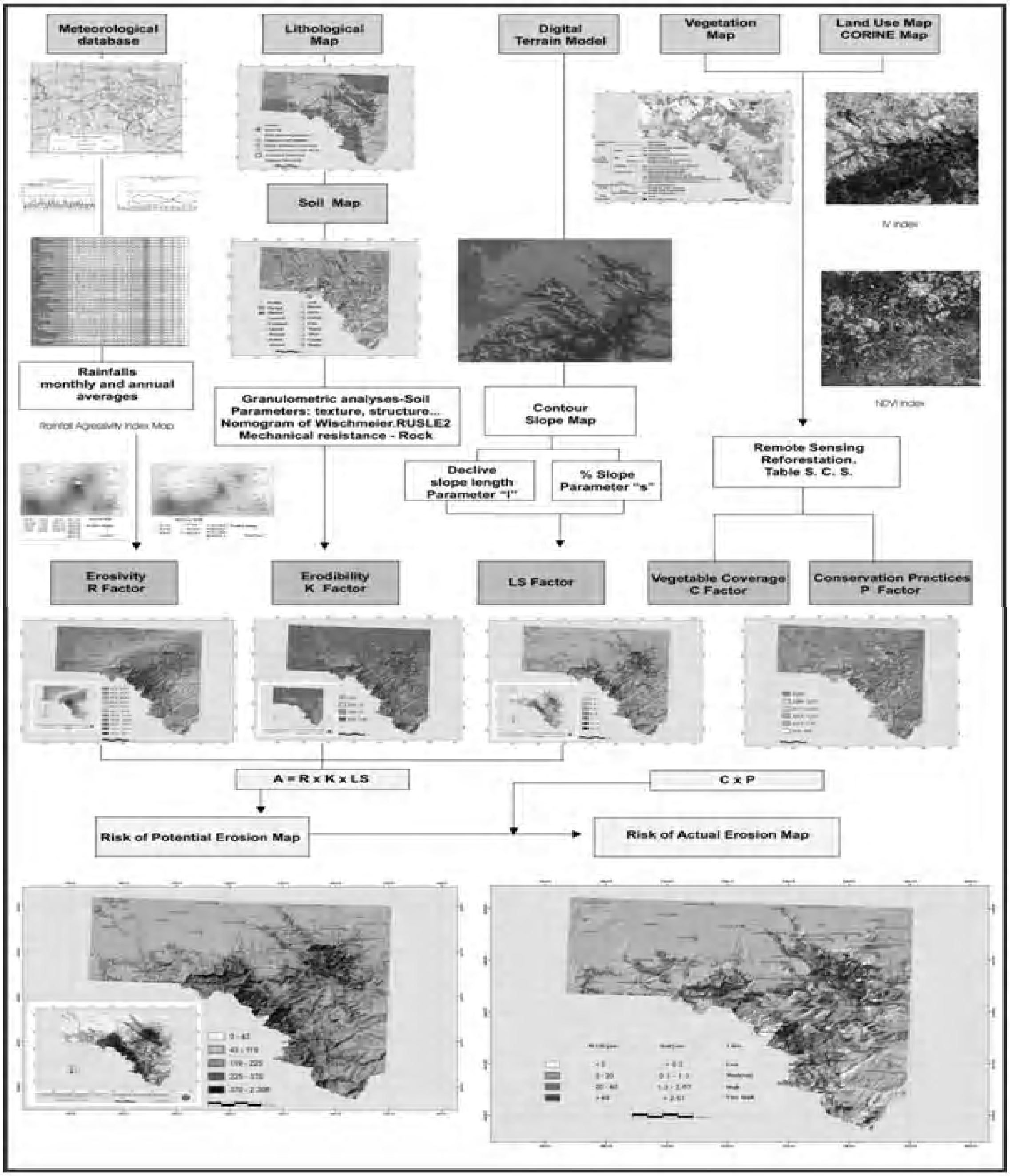


Fig. 3. Schematic of the procedure for calculation of water erosion

analysed using RUSLE, comparing data obtained from the Institute for the Conservation of Nature in its erosive States map (scale 1/200,000) to data from experimental plots. The parameters of texture, structure, organic matter and permeability (Wischmeier and Smith 1978), were applied to the Wischmeier nomogram (Morgan , 2001). K factor values were also validated by empirical formulas for textural parameters (Renard, 1997; ESB, 2000). To do this, from the lithological mapping and soil data, different parameter values were obtained based on the chemical and granulometric analysis of soils in field and laboratory tests, using the regression equation proposed by Wischmeier: 100K= [10^{-4} 2.71 Texture $^{1.14}$ (12- Organic Matter)] + 4.2 (Soil structure-2) + 3.2 (Permeability-3), where K is the K factor, and M is the difference between 100% and the percentage of clay in a soil sample (Morgan, 2001).

The topographic factor LS reflects the need for a thorough understanding of the topography of the area because soil erosion is intensified in the lower areas, where it concentrates. Thus, the slope (subfactor S) and length of slope (subfactor L) must be obtained in order to determine the flow directions and erosive capacity. The use of GIS techniques helps to obtain a digital terrain model based on 1/10,000-scale topographic mapping, resulting in a grid with a spatial accuracy of 20 meters (Gisbert *et al*., 2001). To validate the indexes of the slope (S) and the length of the slope (L) we used the following equations (Morgan ,2001): S = (Sen B / 0.0896) 1.3 and L = 1.4 (As/22.13) 0.4, where B is the slope angle in degrees for each point, and As is the specific contribution surface (pixel size 20 m); 22.13 m is the smallest length of runoff decline and the standard unit of length of the experimental plots. The multiplication of these three factors, R, K and LS, maps the potential erosion risk.

Values of the factor C for ground cover were obtained from vegetation mapping and remote sensing, using the normalised vegetation index or NDVI to estimate the protective effect of vegetation with respect to the degree of soil erosion susceptibility, according to the method proposed by the Soil Conservation Service of the United States (Morgan, 2001). To increase the accuracy of the C factor values, two field studies were carried out, and the vegetation parameters for each spot on the map were determined, taking into account their quantitative assessment (cover type, arboreal height, percentage of tree cover and shrubs and thickness of grass cover and humus).

Finally, the P factor for soil conservation practices was not taken into account, and we need to know the potential and actual losses based on consideration of natural factors. To determine the level of erosion risk mapping, the previous factorswas multiplied by the potential erosion risk factor C, showing the current erosive conditions. The classification of soils into erosion groups is made using the initial classification of the FAO intervals.

Wind erosion

Wind erosion is the process of removal and transport of soil particles by wind. Wind erosion risk is high for large flat areas with fine and loose soils and without obstacles (vegetation or rocks) and is also high in areas with low rainfall, high temperatures and frequent strong winds (Fister and Ries, 2009; Stout, 2012). In the study area, wind erosion results in loss of soil thickness and fertility and is a precursor to desertification. We used a semiquantitative method from a user-friendly mapping process (Fig. 4), which is similar to that developed for water erosion and applicable to any natural area in the world (Quirantes Puertas, 1991).

This methodology involved creating a computerised database. To process the different map–algebra operations, we established a cartographic model using ArcGIS v.10 for automatic calculation of the parameters needed in the procedure and obtained from field and laboratory analysis. We first determined the areas of deflation in the natural parks Las Batuecas–Sierra de Francia and Quilamas , areas with frequent high winds (more than 55 days/year with velocity > 5 m/s), with slopes less than 25% and with a minimum area of 2500 hectares.

The risk of wind erosion is influenced by the type of soil and surface formations in the area, so a series of topographic profiles were obtained from digitised maps of geomorphological domains, differentiating superficial formations (scree, colluvial deposits, foothills, alluvial fans or dejection, glacis, alluvial fans and terraces) and calculating their minimum and maximum slopes. This analysis of superficial formations and pending direct measurement by a digital terrain model, and analyses slopes by reclassifying their mean values.

Next, lithological mapping of soil was conducted to establish the relationship floors, the areas of deflation. Then, we created a database that relates each type of soil to its granulometric and analytical values in the summary of the most representative profile of each floor, based on textural erodibility (ET) and analytical erodibility (EA).(Martínez-Graña *et al*., 2012).

Textural erodibility is calculated from the granulometric composition of soil, considering the percentages of clay, silt and coarse particles (sands and gravels). The analytical erodibility is determined as a function of the carbonate content (the presence of carbonate decreases the formation of aggregates in soil particles, so the higher the percentage of carbonates is, the higher the erodibility is) and organic matter (which is involved in the formation of aggregates that provide stability to the soil; the higher the organic matter content is, the lower the erodibility is). We then added up the maps of textural and analytical erodibility to produce a map of the overall erodibility index (I.e.g.). With overall erodibility mapping and the protection index (IP), we can calculate the wind erosion index (EI) using the following expression: IE = I.e.g - (3 x I.P.), where I.e.g. is the erodibility index (Sierra *et al*., 1991; Takken *et al*., 2005). The wind factor analysis takes into account the National Wind Map at a scale of 1/1 million, yielding an index value (IV) of 1 for the study area, so

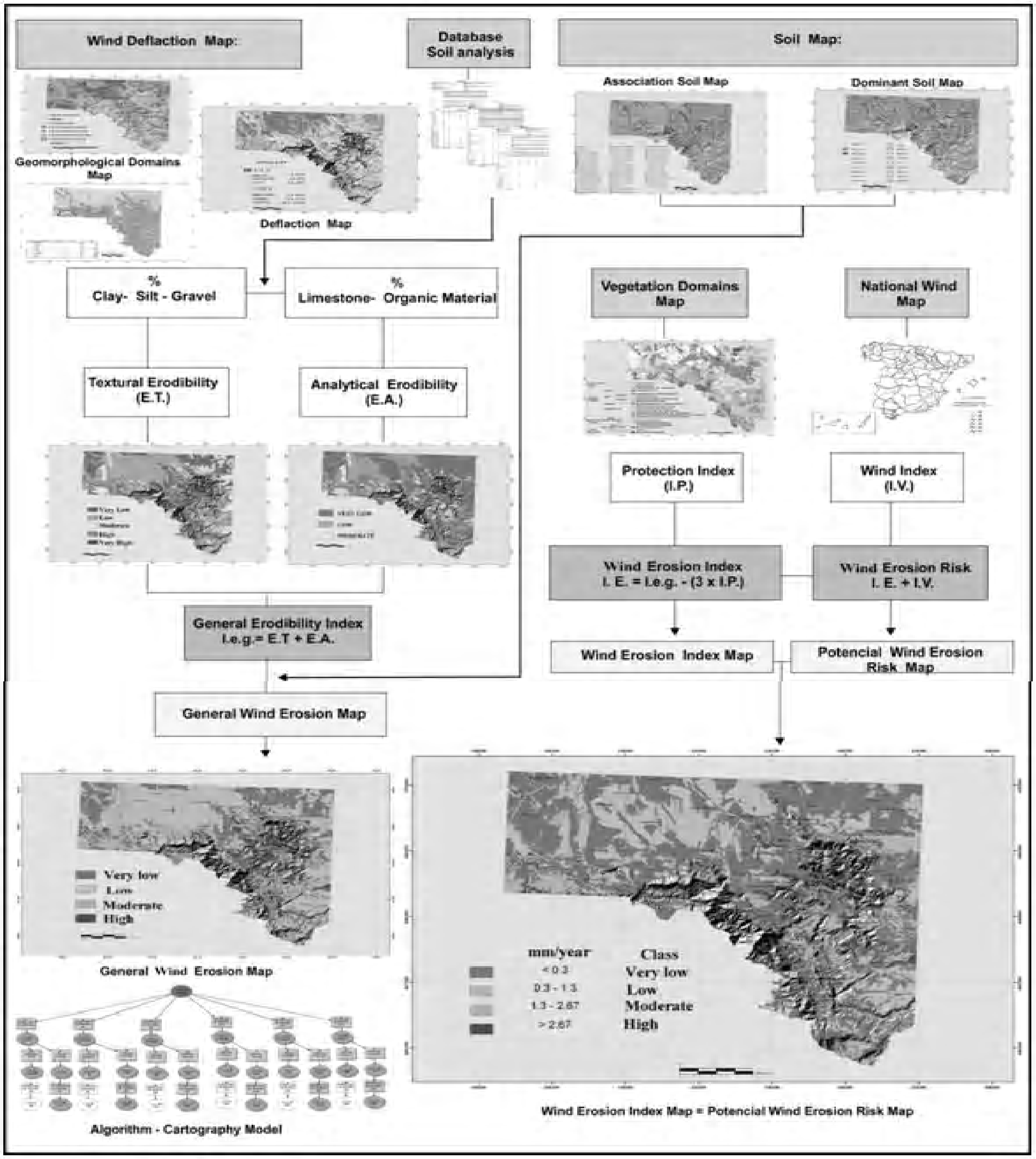


Fig. 4. Schematic of the procedure for calculation of wind erosion

the potential for wind erosion (IE + IV) has the same distribution as the index of wind erosion. We thus obtain a Map of Wind Erosion Risk by adapting the data to the FAO methodology.

RESULTS & DISCUSION

The risk mapping of water and wind erosion (Fig. 5), establishes a zone that identifies the areas of greatest potential soil loss as those with the most rugged topographic conditions, considering water erosion a precursor of desertification, and matches these areas with areas outside the areas of deflation. This process shows serious soil losses of more than 48 t ha^{-1} y^{-1}, or more than 2.6 mm/year, with an average bulk density of 1.29 gr/cm^3. By analysing the actual water erosion risk, we note that it is a factor to consider, given the existence of certain sectors with serious and significant erosion risks. Proper environmental management of these natural areas should consider the magnitudes of these processes and possible mitigation and/or risk reduction.

Areas with current erosion risk that is severe (> 40 t ha^{-1} y^{-1}or > 2.67 mm/year) or significant (20–40 t ha^{-1}

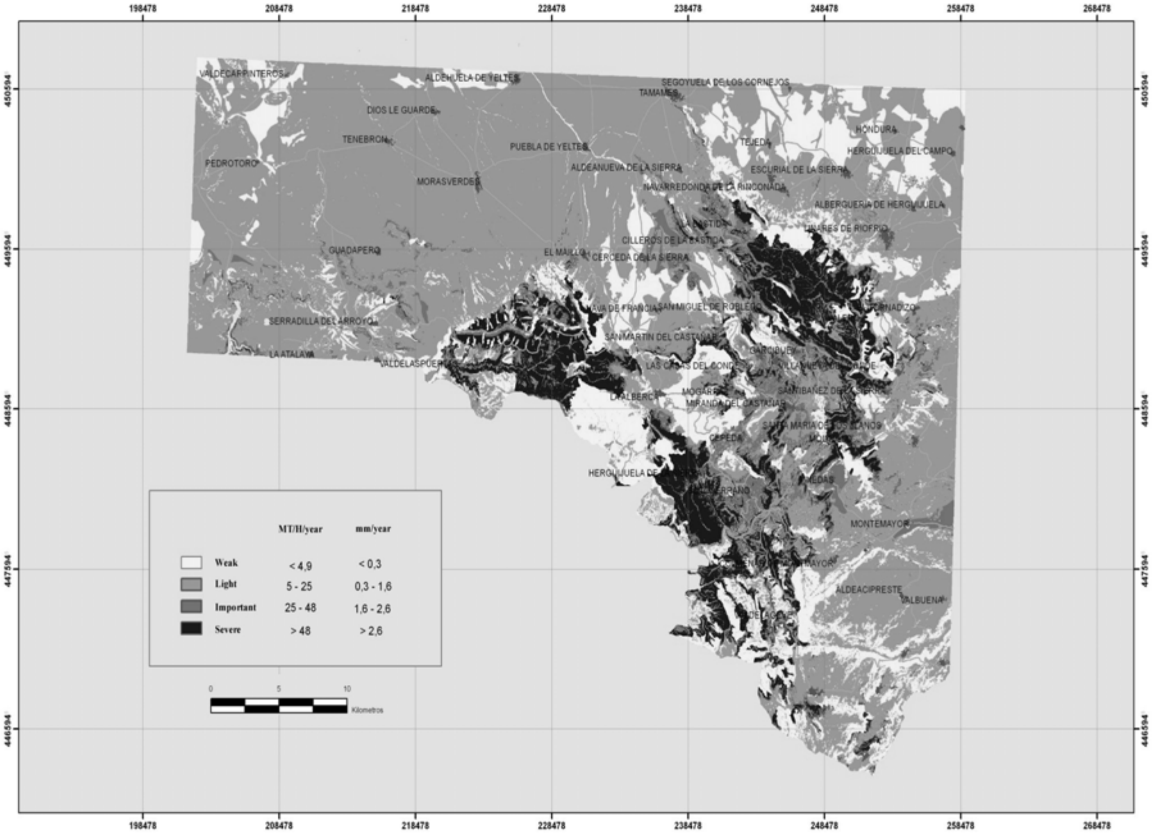


Fig. 5. Mapping the risk of water and wind erosion

y^{-1} or 2.67–1.3 mm/year) were identified. The existing degree of erosion of these areas is mainly due to their rugged topography, steep slopes, abundant rainfall and little or no vegetation cover. Erosion risk is also indicated for other sectors at lower elevations where slopes are strongly affected by fluvial processes or where resistance to lithological weathering processes is weak. Based on analysis of the depth of the A horizon (0.25 cm), the actual water erosion risk is light (5–20 t ha^{-1} y^{-1}or 1.3–0.3 mm/year) in some sectors with significant vegetation cover and without very abrupt relief changes. In some areas between the two mountain ranges where the reliefs are very limited and the vegetation cover is very dense, the lithological factor is very strong. A slight degree of erosion is present in the foothills of the border and coincides with severe erosion risk. The area of weak erosion risk (<5 t ha^{-1} y^{-1} or <0.3 mm/year) is located primarily outside of the natural areas and in the foothills and gently sloping areas (terraces, glacis, alluvial fans, etc.). A sector of weak risk with granite surfaces also exists in the southern part of the study area.

Second, wind erosion can produce significant losses of soil resources over time if a number of conservation practices for different human activities are implemented. Mapping of the wind erosion index shows that the influence of wind erosion is much lower than that of water erosion in the natural areas “Las Batuecas–Sierra de Francia” and “Quilamas”, which have high environmental value. In the areas where water erosion is more intense, wind erosion is non-existent because these areas are located outside the area of influence of wind processes: in areas of deflation not present within the study area, wind erosion risks are classified as very high (> 2.6 mm/ year). The sectors in which the risk of wind erosion is greatest are limited to specific areas such as deep valleys. These areas have low-slope surfaces and very little vegetative cover. As a result, their general index of erodibility is very high, due to their high textural and analytical erodibility. The moderate wind erosion risk is very small and is, distributed over the surface of the adjacent river. The sectors with a low risk of wind erosion are distributed in areas adjacent to natural areas and in the periphery of the mountains. Finally, areas where the risk of wind erosion is nil or very low are predominant in the foothills and river terraces. From this zoning, risk mitigation programs can be developed to assist in selecting preventive and/or corrective actions (ploughing parallel to contours, terraces, etc.) and management or non-structural actions (reforestation and sustainable agricultural practices).

CONCLUSIONS

The combination of GIS techniques and remote sensing with soil analysis are great improvements in estimating the risk of erosion of an area. These techniques were used in this study with relational databases that generate thematic maps of the factors to be considered when applying the USLE-RUSLE models and in the calculation of wind erosion, especially in areas of high spatial and temporal variability, as well as in mapping water and wind erosion risks for any natural park. Risk mapping of water and wind erosion identifies sectors outside the areas of deflation that exhibit serious and severe soil loss due to water erosion. These sectors include mountainous areas with altitudes above 1200 meters and scattered mountain ranges and adjacent nesting reliefs of rivers. Sectors within the areas of deflation have an increased risk of water and wind erosion. The sectors where the risk of erosion is low, even when considering the two types of erosion (water and wind) together, correspond to depressed areas or valley bottoms and surrounding steep areas (colluvial deposits, piedmont, cones, alluvial fans and river terraces). The increase in the erosivity differential in areas of low gradient and cultivated erosion-light is weak, but in areas with little agricultural activity and reliefs, the erosion risk correlated with high analytical and textural erodibility and low vegetation cover.

The erosive response analysis conducted for these natural parks with soil mapping showed that sandy loam soil textures and high clay contents, in addition to silt and organic matter, increase chemical and biological activity by facilitating the formation of aggregates, which reduce erosion phenomena. Instead, soils with a highly developed clay horizon, which in our study area are located on boards and arkoses, present a high infiltration, because the upper level undergoes saturated and active processes that facilitate erosion of the material more than the clay level. The developed procedure provides erosion mapping for hazard zoning that enables sustainable development of mitigation programs for preventive and/or corrective actions that can be undertaken for the management of natural areas.

ACKNOWLEDGEMENTS

Projects CGL2012-33430/BTE and CGL2012-37581-CO2-01.

REFERENCES

Bou Kheir, R. (2008). A conditional GIS-interpolation-based model for mapping soil-water erosion processes in Lebanon. Land Degradation & Development **19**, 122–135.

De Luis, M, González-Hidalgo, J.C. and Longares, A. (2010).Is rainfall erosivity increasing in the Mediterranean Iberian Peninsula?. Land Degradation & Development **21**, 139–144.

ESB, (2000). European Soil Bureau-Scientific Committee, Una base de datos georeferenciada de suelos para Europa. Manual de procedimientos v. 1.1. European Soil Bureau-Scientific Committee, European Commission, Joint Research Centre, SAI-ESB, Italy.

Gisbert Blanquer, J. M., Ibáñez Asensio, G., Andrés Aznar, A. and Marqués Mateu, A. (2001). Estudio comparativo de diferentes métodos de cálculo del factor “LS” para la estimación de pérdidas de suelo por erosión hídrica. Edafología, **8**, 57-66.

Stout, J. E. (2012). A field study of wind erosion following a grass fire on the Llano Estacado of North America. Journal of Arid Environments, **82**, 165-174.

López , V. and Navas, A. (2010). Routing runoff and soil particles in a distributed model with GIS: Implications for soil protection in mountain agricultural landscapes. Land Degradation & Development, **21**, 100–109.

Martínez-Graña, A. M., Goy, J. L. and Zazo, C. (2012). Cartographic procedure for the analysis of aeolian erosion hazard in natural parks (Central System, Spain). Land Degradation. Doi:10.1002/ldr.2189.

Morgan, R.P.C. (2001). A simple approach to soil loss prediction: a revised Morgan–Morgan–Finney model. Catena, **44**, 305–322.

Quirantes Puertas, J. (1991). Métodos para el estudio de la erosión eólica. Estación Experimental del Zaidín (C.S.I.C.). Ed. Geoformas, pp 210.

Sierra C., Quirantes J. and Lozano J. (1991). Uso del suelo y erodibilidad eólica (Depresión Guadix-Baza). In “Soil Erosión Studies in Spain. Ed. Geoforma, pp 255.

Takken, I, Govers, G, Jetten, V, Nachtergaele, J, Steegen, A. and Poesen, J. (2005). The influence of both process descriptions and runoff patterns on predictions from a spatially distributed soil erosion model”. Earth Surface Processes and Landforms, **30**, 213–229.

Fister, W. and Ries, B. (2009). Wind erosion in the central Ebro Basin under changing land use management. Field experiments with a portable wind tunnel. Journal of Arid Environments, **73**, 996-1004.

Wischmeier W. H. and Smith D.D. (1978). Predicting rainfall erosion losses: A guide to conservation planning, U. S. D. A. Agriculture Handbook nº 537, Washington D.C.

Cantón, A. Solé-Benet J. De Vente, C. Boix-Fayos, A. Calvo-Cases, C. and Asensio, J. (2011). A review of runoff generation and soil erosion across scales in semiarid south-eastern Spain. Journal of Arid Environments, **75**, 1254-1261.