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Estimating rainfall erosivity from daily precipitation records: A comparison among methods using data from the Ebro Basin (NE Spain)

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SUMMARY

Among the major factors controlling soil erosion, as vegetation cover or soil erodibility, rainfall erosivity has a paramount importance since it is difficult to predict and control by humans. Accurate estimation of rainfall erosivity requires continuous rainfall data; however, such data rarely demonstrate good spatial and temporal coverage. Daily weather records are now commonly available, providing good coverage that better represents rainfall intensity behavior than do more aggregated rainfall data. In the present study annual rainfall erosivity was estimated from daily rainfall records, and compared to data obtained employing the RUSLE *R* factor procedure. A spatially-dense precipitation database of high temporal resolution (15 min) was used. Two methodologies were applied: (i) daily rainfall erosivity estimated using several parametric models, and, (ii) annual rainfall erosivity estimated by regression-based techniques employing several intensity precipitation indices and the modified Fournier index. To determine the accuracy of estimates, several goodness-of-fit and error statistics were computed in addition to a spatial distribution comparison. The daily rainfall erosivity models accurately predicted annual rainfall erosivity. Parametric models with few combined parameters and a periodic function simulating intra-annual rainfall behavior provided the best results. Where daily rainfall records were not available, good estimates of annual rainfall erosivity were also obtained using regression-based techniques based on 5-day maximum precipitation events, the maximum wet spell duration, and the ratio between the lengths of average wet and dry spells. Inherent limitations remain in the use of daily weather records for estimating rainfall erosivity. Future research should focus on incorporating measures of natural rainfall properties of the particular region, including kinetic energy and intensity, and their effects on the soil.

Introduction

Rainfall erosivity is of paramount importance among natural factors affecting soil erosion, and unlike some other natural factors, such as relief or soil characteristics, is not amenable to human modification. It thus represents a natural environmental constraint that limits and conditions land use and management. In the context of climate change the effect of altered rainfall characteristics on soil erosion is one of the main concerns of soil conservation studies.

It is well known that several very intense rainfall events are responsible for the largest proportion of soil erosion and sediment delivery. Hence, estimating rainfall erosivity is central to assessment of soil erosion risk. Numerous studies using natural and simulated rainfall have investigated the role of drop size distribution on the detachment of soil particles. The measurements involved are difficult to perform, and reported data are consequently very limited both spatially and temporally. In addition, measurements of natural rainfall properties, for comparison with simulated rain, are scarce (Dunkerley, 2008). This has encouraged studies relating more conventional rainfall indices, such as the maximum intensity during a period of time, to overall rainfall energy or directly to soil detachment rates. Examples of such indices of rainfall erosivity are the USLE *R* factor, which summarizes all the erosive events quantified by the EI_{30} index occurred along the year (Wischmeier, 1959; Wischmeier and Smith, 1978; Brown and Foster, 1987), the modified Fournier index for Morocco (Arnoldus, 1977), the KE > 25 index for southern Africa (Hudson, 1971), and the AIm index for Nigeria (Lal, 1976). Among these the most extensively used is the USLE/RUSLE *R* factor, which is calculated from the EI_{30} index (Wischmeier, 1959; Wischmeier and Smith, 1978; Brown and Foster, 1987; Renard et al., 1997). At many sites worldwide the *R* factor has been shown to be highly correlated with soil loss (Van der Knijff et al., 2000; Diodato, 2004; Shi et al., 2004; Hoyos et al., 2005; Curse et al., 2006; Onori et al., 2006; Domínguez-Romero et al., 2007).

One of the main disadvantages in seeking to employ the RUSLE *R* factor is the need for a relatively continuous rainfall data series, with a time resolution of at least 15 min (pluviograph data).

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Information of this nature is rarely available with good spatial and temporal coverage. Other attempts to predict rainfall erosivity from mean annual rainfall and/or mean monthly rainfall have provided results that are quite coarse, but these have been extensively cited in the scientific literature (Banasik and Górski, 1994; Renard and Freimund, 1994; Yu and Rosewell, 1996c; Ferro et al., 1999). Renard and Freimund (1994) provided a succinct summary of methods for estimating the *R* factor in various parts of the world, and also developed a new set of relationships for calculating the *R* factor using mean annual rainfall data and the modified Fournier index.

Daily weather records with good spatial and temporal coverage that adequately represent rainfall characteristics are usually available for most locations. Because of the high temporal and spatial variability of rainfall erosivity, accurate records based on long data series are required. Attempts to accurately predict rainfall erosivity from daily rainfall records or storm events (Richardson et al., 1983; Bagarello and D'Asaro, 1994; Petkovsek and Mikos, 2004), or from monthly rainfall (Yu and Rosewell, 1996a,b,c; Yu et al., 2001), have been based largely on exponential relationships.

As the origin of rainfall erosivity is linked to climate dynamics, there is a need to apply climate analysis methodologies to the study of the erosivity factor. However, long series of rainfall erosivity data are required if consistent results are to be obtained. Daily rainfall erosivity models bridge the gap between climate change scenarios based on general and regional circulation models, and the implications of these scenarios for some land degradation processes (Yu and Rosewell, 1996b). In addition, a daily rainfall erosivity model would have potential application in many erosion constructs, as the daily model would provide robust predictions of rainfall erosivity.

The aim of this study was to review existing methodologies for predicting the *R* factor, and to compare estimates obtained using these methodologies with *R* factor values calculated by the RUSLE procedure. The study was conducted using data from a dense network of observatories distributed in a climatically complex region (the Ebro Basin, NE Spain), and covers the period 1997–2006. The methodology described has the potential to be applied to longer daily rainfall data bases, which could improve estimates of the spatial coverage of rainfall erosivity in the Ebro Basin with respect to both long-term average erosivity and seasonal distribution thereof. The proposed methodology can be applied in many parts of the world where short time series of high-resolution rainfall data coexist with long series at a daily resolution.

Materials and methods

Study area

The study area covers northeastern Spain (Fig. 1), encompassing an area of about 85,000 km^2 that corresponds to the Ebro Basin. The Ebro valley is an inner depression surrounded by high mountain ranges. It is limited in the north by the Cantabrian Range and the Pyrenees, with maximum elevations above 3000 m a.s.l. The Iberian Range closes the Ebro valley to the south, with maximum elevations in the range 2000–2300 m a.s.l. The Ebro valley is closed to the east by the Catalan Prelittoral Range, with maximum elevations of 1000–1900 m a.s.l.

The climate is influenced by the Cantabric and Mediterranean Seas, and the effect of the relief on precipitation and temperature. The bordering mountain ranges isolate the central valley, blocking the maritime influence and resulting in a continental climate with arid conditions (Cuadrat, 1991; Lana and Burgueño, 1998; Creus, 2001; Vicente-Serrano, 2005). A climatic gradient in the NW–SE direction is notable, determined by the strong Atlantic Ocean influences in the north and northwest of the area during much of the year, and the influence of the Mediterranean Sea to the east. The mountain ranges add complexity to the climate of the region. The Pyrenees extend the Atlantic Ocean influence to the east by increasing precipitation.

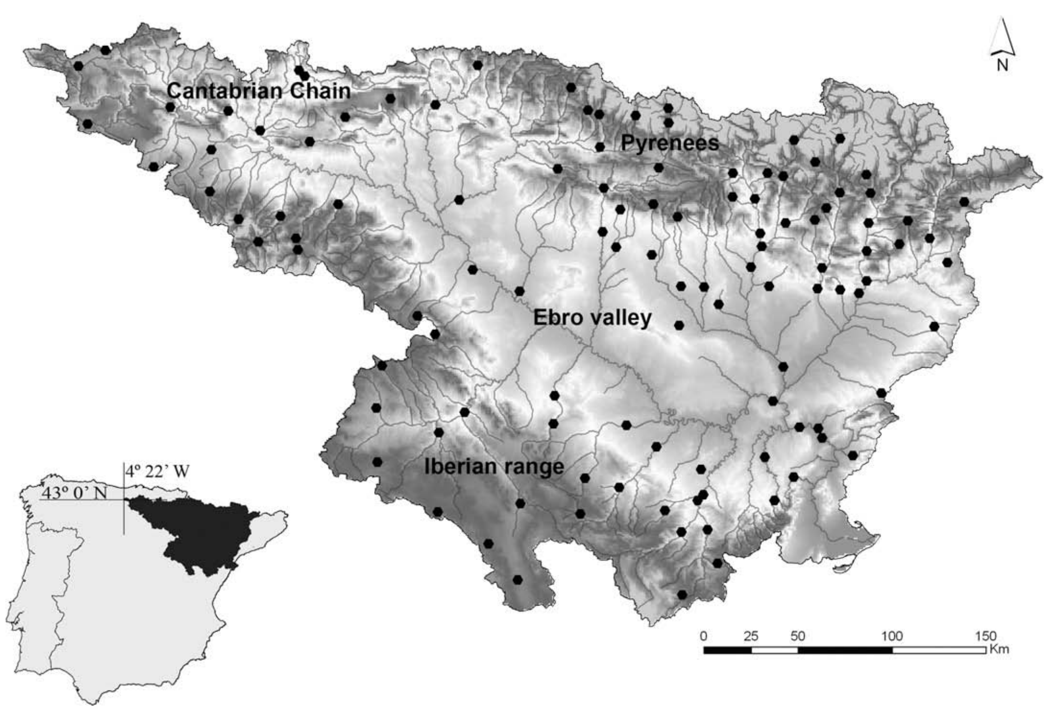

Fig. 1. Location of the study area and the precipitation observatories of the SAIH network. As it is part of a hydrological warning and control system, the SAIH network is not evenly distributed; more importance is placed on headwater areas at the borders of the study area. However, this distribution coincides with the spatial variation of rainfall characteristics, which shows small spatial variance in the center of the Ebro Basin and maximum spatial variance towards its margins.