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Effect of temporal resolution on rainfall erosivity estimates in zones of precipitation caused by frontal systems

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ABSTRACT

The *R*-factor of the Universal Soil Loss Equation is a commonly used erosivity index for predicting soil loss from agricultural hillslopes. This factor is calculated from the total kinetic energy (*E*) and the maximum 30-min rainfall intensity of a storm (I_{30}), requiring sub-hourly rainfall information. However, sub-hourly rainfall data are usually scarce worldwide, whereas hourly and other coarser resolutions are readily available. This paper analyzes the sensitivity of rainfall erosivity to the temporal resolution in zones of precipitation produced by frontal systems and proposes a method to compute it using rainfall records with a resolution of up to 24 h. Hourly pluviographic records from 30 sites located in Central Chile (415 years of data and 18,012 storms) were aggregated to obtain temporal resolutions of 1 to 24 h. Rainfall erosivity, I_{30}, and *E* were computed for all the sites, in addition to the conversion factors to estimate their values with different temporal resolutions. Rainfall erosivity and I_{30} showed a nonlinear relationship with temporal resolution for a time interval of 1–24 h, whereas *E* was practically unaffected by the timespan. However, the conversion factors for erosivity, I_{30}, and *E* proved to have a linear relationship with temporal resolution (R^2 between 0.89 and 0.99). The similarity between the regression lines of the conversion factors of rainfall erosivity and I_{30} shows that the sensitivity of erosivity to the temporal resolution of rainfall data is controlled almost entirely by I_{30}. However, the regression lines of the *E* conversion factors, with average slopes of 0.01, intercepts of 0.99 and R^2 of 0.89, demonstrated that *E* is not sensitive to temporal resolution in the study sites. By extending the regression lines of the conversion factors to a time interval of 0.5-h, rainfall erosivity and I_{30} were predicted for a temporal resolution of 0.5 h. The results were compared with those obtained using non-linear IDF curves, as no 0.5-h rainfall records are readily available for the study sites. Significant similarities were found between the methods ($R^2 = 0.99$), showing that, for frontal systems the simple linear regressions obtained in this study can provide the same erosivity and I_{30} as nonlinear IDF curves.

1. Introduction

Rainfall erosivity is defined as the ability of rainfall to detach soil particles (van Dijk et al., 2002). Some of the most widely used indices of rainfall erosivity include a measure of rainfall kinetic energy and a correction factor that addresses the fact that kinetic energy is not linearly related to erosivity (Govers, 1991; Hudson, 1961; Salles and Poesen, 2000; Torri et al., 1897). One such index corresponds to the *R*-factor of the Revised Universal Soil Loss Equation RUSLE (Renard et al., 1997), a widely used erosivity index that has been tested and validated in several countries across the world (Foster, 2008; Fox, 2004; Johnson et al., 1996; Mikhailova et al., 1997; Nearing et al., 2005; Nyssen et al., 2005; Sharpley and Williams, 1990; Yin et al., 2007). The *R*-factor is defined as the average of the annual summations of each storm's erosivity (EI_{30}), which is computed for every storm as the product of kinetic energy (*E*) and the maximum 0.5-h rainfall intensity (I_{30}) (Renard et al., 1997). Thus, estimating the *R*-factor requires having a reliable measure of rainfall kinetic energy and also reliable sub-hourly rainfall measurements.

At best, EI_{30} is computed using breakpoint rainfall intensity data derived from recording rain gauges (Foster, 2008; Renard et al., 1997). However, there is a limited number of meteorological stations worldwide that actually record breakpoint data (Shamshad et al., 2008). With the development of automatic weather stations, fixed time-interval rainfall data at various temporal resolutions are becoming more easily available and more widely used (Yin et al., 2007). Because these stations often use time steps of 1-h or more, several techniques that estimate the *R*-factor from numerous temporal resolutions have been developed, including sub-hourly, hourly and daily rainfall data

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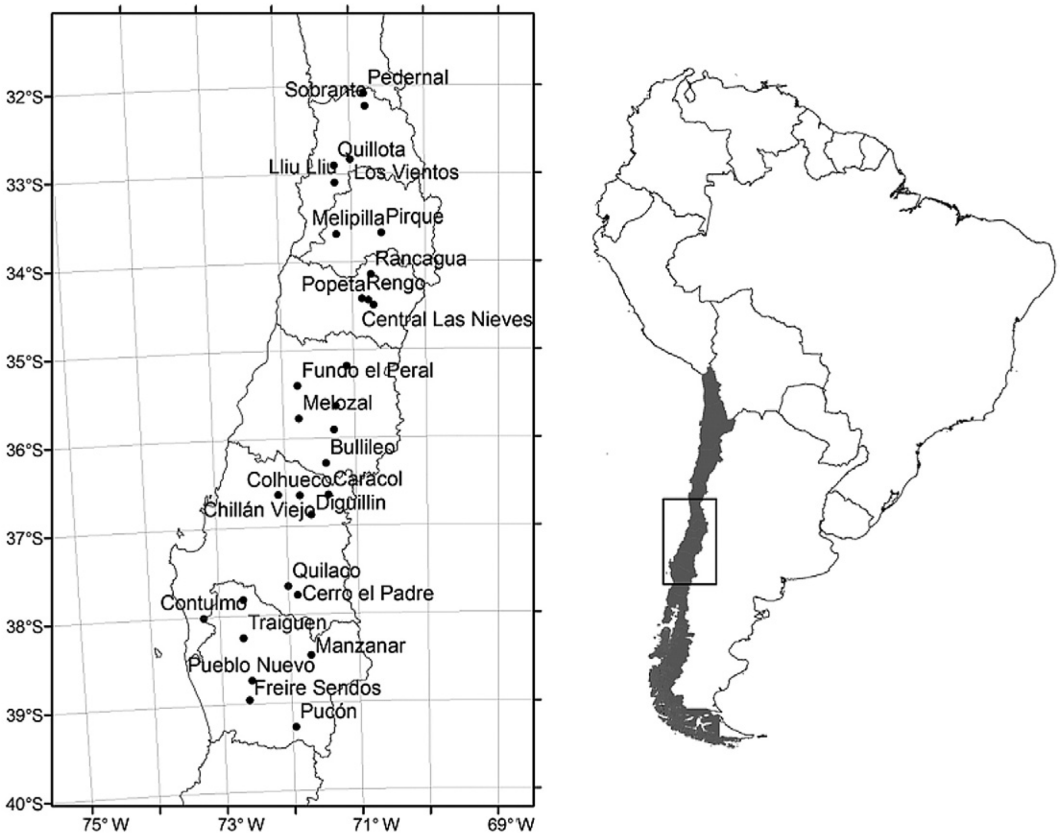

Fig. 1. Spatial distribution of the meteorological stations used in the study.

(Ateshian, 1974; Ferro et al., 1991; Renard and Freimund, 1994; Yu and Rosewell, 1996). These techniques include the conversion factors developed in the studies of Weiss (1964), Istok and McCool (1986) and Yin et al. (2007), which relate the *R*-factor computed using fixed-time intervals with the *R*-factor computed using breakpoint data. Additionally, indices that relate daily precipitation to rainfall erosivity have been developed and tested, such as the modified Fournier Index (Arnoldus, 1980; Morgan, 1986; Silva da, 2004). Nevertheless, most of these techniques have proven to be highly site-dependent, making them inaccurate in climates different to those used to develop them (Williams and Sheridan, 1991).

Time intervals in automatic weather stations are usually set to 1-h, which only allow for the calculation of $R_{\Delta 1}$ (the rainfall erosivity obtained using 1-h fixed time rainfall records). However, for many reasons, such as storage economy, this resolution can be even smaller (e.g., intervals of 2 or more hours). As details from the rainfall data are lost, the estimation of the *R*-factor becomes less accurate (Shamshad et al., 2008; Yin et al., 2007). However, it is not clear as to what degree the temporal resolution of the rainfall records affects accuracy, especially at time steps larger than 1-h, as most studies focus on sub-hourly measurements (Yin et al., 2007). This adds uncertainty when computing the *R*-factor in sites where the temporal resolution of the rainfall records is larger than 1-h. Therefore; the objective of this study was to quantify the loss of precision of the *R*-factor when decreasing the resolution of fixed-interval rainfall data using climatic data from 30 sites located in Central Chile. The different effects that E and I_{30} have in the estimation of the *R*-factor at various temporal resolutions were also analyzed, providing relationships for estimating rainfall erosivity from precipitation data measured at different time intervals. These results are intended to improve the estimation of rainfall erosivity using low-resolution rainfall records in Central Chile and in other sites where frontal systems predominate.

2. Materials and methods

2.1. Study sites and rainfall data

Hourly pluviographic records were used to compute rainfall erosivity values on 30 sites located in Central Chile using various temporal resolutions. These records were obtained from the meteorological stations shown in Fig. 1, which are distributed between latitudes 32°04′S and 39°47′S. The stations are part of two national rain gauge networks managed by the Dirección General de Aguas (DGA) and the Sistema Nacional de Calidad del Aire (SINCA). As shown in Table 1, the amount of data per station ranged from 3 to 28 years, adding up to a total of 418 years and 18,012 storms. Depending on the station, the rainfall data were recorded between 1970 and 2013, with missing annual data at some stations. The climate in this portion of Chile is mainly semi-arid and the rainfall is usually of a frontal nature (Escobar and Aceituno, 1998), with intensities that rarely exceed 5.5 mm h^{-1} (Table 1). Also, the rainfall is highly erosive in some areas, and the precipitation amount increases with latitude (Bonilla and Vidal, 2011; Lobo et al., 2015).

2.2. Estimation of EI_{30} and the R-factor

The rainfall erosivity of each individual rainfall event (EI_{30}) was computed using the relationship proposed in the RUSLE (Renard et al., 1997), in which rainfall erosivity is defined as the product of the event's kinetic energy E (MJ ha^{-1}), and the maximum 0.5-h rainfall intensity I_{30} (mm h^{-1}). Kinetic energy for every event was computed as follows (Foster, 2008):

$$E_{\Delta t} = \sum_{r=1}^{\Delta t} 0.29[1-0.72\exp(-0.082 i_r)]\Delta V_r \qquad (1)$$