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Article

Evaluation of Erosivity Index (EI) in Calculation of R Factor for the RUSLE

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The Revised Universal Soil Loss Equation (RUSLE) is a revision of the Universal Soil Loss Equation (USLE). However, changes for each factor of the USLE have been made in RUSLE which can be used to compute soil loss on areas only where significant overland flow occurs. RUSLE which requires standardized methods to satisfy new data requirements estimates soil movement at a particular site by utilizing the same factorial approach employed by the USLE. The rainfall erosivity in the RUSLE expressed through the R-factor to quantify the effect of raindrop impact and to reflect the amount and rate of runoff likely is associated with the rain. Calculating the R-factor value in the RUSLE equation to predict the related soil loss may be possible to analyse the variability of rainfall erosivity with long time-series of concerned rainfall data. However, daily time step models cannot return proper estimates when run on other specific rainfall patters such as storm and daily cumulative precipitation. Therefore, it is desirable that cross-checking is carried out amongst different time-aggregations typical rainfall event may cause error in estimating the potential soil loss in definite conditions.

Key words: Soil loss, RUSLE, R factor, Erosivity index, Rainfall intensity

Introduction

Soil loss by water is regarded as one of the crucial environmental problems. Eroded soils which can include various materials such as nutrients, pesticides, and other harmful chemicals can be transported into rivers, streams, and ground water resources (Gallaher and Hawf, 1997). The most general impairment of surface water is eutrophication caused by excessive inputs of phosphorus and nitrogen, which affects on the aquatic ecosystems (Carpenter et al., 1998). Research on soil erosion and its effect from the viewpoint on agricultural productivity started in the United States in 1930s. Since then research scientists began to develop a quantitative procedure for estimating soil loss using soil loss equation including several primary factors such as slope and practice in the United States, because it was recognized that a soil loss equation could have a great value for farm planning (http://www.iwr.msu.edu/rusle).

The USLE has been widely used to predict rainfall erosion losses resulting from various crop and management practices (Wischmeier and Smith, 1965, 1978). RUSLE has the same formula as USLE, but has several improvements in determining factors adopting a time-varying approach for soil erodibility factor and a new equation to reflect slope length and steepness (Renard and Ferreira, 1993; Renard et al., 1997; Wischmeier and Smith, 1965, 1978).

Importance of Rainfall erosivity used as an input parameter not only for modeling soil erosion but also for sediment yield and water quality modeling has been grown. Thus, the accurate estimation of rainfall erosivity may contribute to better modeling results (Renard et al., 1997). The rainfall and runoff factor (R) of USLE, which was developed initially as a tool to estimate soil loss on specific slopes in specific fields to estimate the possible cropping intensity for alternative conservation measures for given cropping and management practices while meeting the needs and wishes of the farmer in farm planning, was derived from research data from many sources (Wischmeier 1959, Wischmeier and Smith 1958). The results represent that soil losses from cultivated fields are directly proportional to a rainstorm parameter when factors

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other than rainfall are held constant. That is, R can be interpreted as the total storm energy (E) times the maximum 30-min intensity (I_{30}).

Unceasing rainfall data is required to calculate R factor although the spatial and temporal coverage of pluviograph data are generally limited (Yu and Rosewell, 1998). For this reason, many methods for predicting R factor have been developed by applying daily, monthly, annual rainfall data (Amoldus, 1980; Ferro et al., 1991; Renard and Freidmund, 1994; Zhang et al., 2008). The objective of this study is to review existing methodologies for predicting rainfall erosivity, and to compare estimates obtained using these methodologies with R factor values calculated by the RUSLE procedure.

Nonpoint source pollution and soil erosion Nonpoint source (NPS) pollution, unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. The runoff picks up and carries away natural and human-made pollutants as it moves and finally arrives to deposit them into lakes and rivers (http://www.epa.gov/owow_keep/NPS/index.html).

In areas with intensive rainfall, agricultural land tends to be non-point source pollutants which enter the water when soil particles are conveyed into the water system, such as lake, river. Nonpoint source pollution usually occurs when rainfall and runoff move over the ground, conveying pollutants with soil particles. Therefore, nonpoint source pollution from agriculture tends to be determined by the amount of rainfall and its intensity.

Soil erosion The loss of soil from land surfaces by erosion is widespread and adversely affects the productivity of all natural ecosystems as well as agricultural, forest, and rangeland ecosystems (Lal and Stewart, 1990; Pimentel, 1993; Pimentel et al., 1995; Pimentel and Kounang, 1998). Soil erosion results when soil is exposed to the erosive powers of rainfall energy and flowing water (Barfield,et al. 1983). Rain along with the shearing force of flowing water acts to detach soil particles, while runoff transports the soil particles downslope.

The processes of soil erosion by rain reaching the ground are closely related to the pathways taken by rain in its movement through the vegetation cover and over the ground surface. The rain reaching the ground may be stored in small depressions or hollows on the surface or it may infiltrate the soil, to lateral movement downslope within the soil as subsurface or interflow or, by percolating deeper, to groundwater. When the soil is unable to take in more water rain reaching the ground, the excess contributes to runoff on the surface, resulting in erosion by overland flow or by rills and gullies.

RUSLE The soil loss as an average erosion rate computed by RUSLE is the amount of sediment lost from a landscape profile which is defined by a slope length, which is the length from the origin of overland flow to the point where the flow reaches a major flow concentration or a major area of deposition. Erosion estimated by soil movement at a particular site can vary widely even on a uniform slope due to slope position and configuration of the slope profile (Jung et al., 2004; Kim et al., 2010).

Estimation of soil loss by the model must be undertaken before implementing the best management practice because it was difficult to measure soil loss directly. Therefore the USLE has been the most widely accepted and utilized soil loss equation for ove 40 years (Wischmeier and Smith, 1965 and 1978; Laflan and Moldenhauer, 2003).

Wishmeier (1976) also explained that the USLE was designed to guide the selection of conservation practices for specific sites, However, the equation is not recommended for geographic regions where its factors cannot be accurately evaluated, for computing soil erosion from specific rainfall events. RUSLE that utilizes the same basic equation as of USLE has been known to be scientifically superior to the USLE. The RUSLE relates the rate of erosion per unit area (A) to the erosive power of the rain (R), the soil erodibility (K), the land slope and length (LS), the degree of soil cover (C), and conservation practices (P) (Renard et al., 1997).

$$A = R \times K \times LS \times C \times P \quad (1)$$

USLE erosivity calculations in the western U.S. were based on the use of a very few weather stations to

Table 1. The differences between RUSLE and USLE.

Factor	USLE	RUSLE
R	Based on long-term average rainfall conditions for specific geographic areas in the U.S.	• RUSLE computes a correction to R to reflect the effect of raindrop impact for flat slopes striking water on the surface.
K	Based on soil texture, organic matter content, permeability, and other factors inherent to soil type	• Same as USLE but adjusted to account for seasonal changes such as freezing and thawing, soil moisture, and soil consolidation.
LS	Based on length and steepness of slope, regardless of land use.	• Assigning new equations based on the ratio of rill to interrill erosion, and accommodates complex slopes.
C	Based on cropping sequence, surface residue, surface roughness, and canopy cover, with are weighted by the percentage of erosive rainfall during the six crop stages.	• Uses the sub-factors: prior land use, canopy cover, surface cover, surface roughness, and soil moisture. • Refines USLE by dividing each year in the rotation into 15-day intervals. • Provides improved estimates of soil loss changes throughout the year, especially relating to surface and near-surface residue and the effects of climate on residue decomposition.
P	P factor values change according to slope ranges with some distinction for various ridge heights.	• P factor values are based on hydrologic soil groups, slope, row grade, ridge height, and the 10-year single storm erosion index value.

develop a relationship between the R factor and the 2-yr frequency 6-hr duration rainfall event. In contrast, erosivity values in RUSLE are based on analysis of data from over 1,000 weather stations (Wischmeier and Smith, 1978). There are many changes for estimating erosion by water in RUSLE. The differences between RUSLE and USLE are represented in Table 1.

Rainfall-runoff factor (R-factor) To estimate the soil loss or soil erodibility at particular site, the numerical value of a rainfall and runoff factor (R-factor) derived from research data from many sources on precipitation by keeping the factors other than rainfall constant, is needed (Wischmeier and Smith, 1958). Originally, the USLE was used with an annual R value to predict annual erosion yields. R, the rainfall-runoff erosivity factor as an indication of the two most important characteristics of a storm determining its erosivity over and extended period, is the average annual summation EI values in a normal year's rain although it has a number of limitations and requires adaptation for different climatic regions (http://www.iwr.msu.edu/rusle/contact.htm). The soil loss from a cultivated field is directly proportionate to the following characteristics of a storm: the product of total kinetic energy of rainfall (E) and its peak 30-minute intensity (I_{30}).

The R-factor is measured as the product (EI_{30}) of total storm energy (E) and the maximum 30-min intensity (I_{30}) for all storms over a long time (Brown and Foster, 1987; Renard and Freidmund, 1994; Wischmeier and Smith, 1978; Istok et al., 1986; Williams and Sheridan, 1991). However, storms less than 0.5 inches are not included in the erosivity computations because these storms generally add little to the total R value (Janeček et al., 2006). The R factor is defined as (Renard et al., 1997):

$$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m}(EI_{30})_k\right]_j$$

where E is the total storm kinetic energy (MJ ha^{-1}), I_{30} is the maximum 30 min rainfall intensity (mm hr^{-1}), j is an index of the number of years used to produce the average, k is an index of the number of storms in each year, n is the number of years used to obtain the average R, and m is the number of storms in each year (Renard et al., 1997). An event's rainfall erosivity EI_{30} is calculated as follows:

$$EI_{30} = \left(\sum_{r=1}^{0} e_r v_r\right) I_{30}$$

where e_r and v_r are, the unit rainfall energy and the rainfall volume during a time period r, and I_{30} is the maximum rainfall intensity in a 30 min period during the event.

For EI calculations, a break between storms is defined as 6 h or more with less than 1.3 mm of precipitation. Rains less than 13 mm, and separated from other storms by 6 or more hours, are moitted as insignificant unless the maximum 15 min intensity exceeds 24 mm h^{-1} (Wischmeier and Smith, 1978). The rainfall energy (e_r) is calculated for each time interval as:

$$e_r = 0.29[1 - 0.72\exp(-0.05 i_r)]$$

where i_r is the rainfall intensity during the time interval (mm hr^{-1}).

Many typical empirical relationships developed in different areas of the world for calculating E from the measured intensities are shown as in Table 2. However these equations use different term depending on the conditions, resulting in different estimates of soil losses for a given conditions.

Table 3 shows typical empirical event's rainfall erosivity equations developed in different areas of the world for calculating R. Diodato (2004, 2005) developed EI_{30} using precipitation patters such as annual, daily, or hourly basis to be used for calculation of R factor as shown in Table 2. Similar to the results of R factor calculation, there were also big differences depending on the precipitation for each equation of EI. Also the precipitation used in this calculation may not be suitable for estimating soil losses by soil erosive forces because it do not consider the balance between infiltration rate and precipitation that can cause runoff over the field. Therefore, it has to incorporate the independent precipitation level that may exceed infiltration rate for a given field.

Table 2. Typical empirical rainfall factor equations developed in different areas of the world for calculating E.

R factor equation	Remarks
$R = E \times I30/100$ $E = \sum_{i=1}^{n} Ei$ $E_i = (206 + 87 \log Isi) \times Hsi$	E : total kinetic energy of rainfall (J/m²) E_i : kinetic energy of the i-th segment of rainfall (*n :* number of rainfall segments) I_{30} : peak 30-min. intensity of rainfall (cm h^{-1}) Isi : intensity of the i-th segment of rainfall (cm h^{-1}) Hsi : rainfall amount in the i-th segment (cm)
$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m}(EI_{30})_k\right]_j$	Brown and Foster(1987) EI_{30} = Total storm energy (E) and the maximum 30-min intensity
R = 38.46+3.48P R = N h^{-1} yr^{-1}	Lo et al. (1985) P= annual average precipitation (mm)
$R = 0.04830P^{1.610}$ $R = 587.8-1.219P+0.004105P^2$	(P < 850 mm) (P > 850 mm) P= annual average precipitation(mm)

Table 3. Typical empirical event's rainfall erosivity equations developed in different areas of the world for calculating R.

R factor equation		Remarks
Annual	$EI_{30\text{-annual}} = 12.142(abc)^{0.6446}$	Diodato (2004) a = annual precipitation (cm) b = annual maximum daily precipitation (cm) c = annual maxi. hourly precipitation (cm)
	$EI_{30-annual} = 0.297(\sum_{i=1}^{n} P_i^2/P)^{1.93}$	Pi = mean monthly rainfall (mm) P = mean annual rainfall (mm) n = 12months
Monthly	$EI_{30-month} = 0.1174 \cdot (\sqrt{m} \cdot d^{0.53} \cdot h^{1.18})$	Diodato (2005) m = monthly precipitation amount (mm) d = monthly max. daily precipitation (mm) h = monthly max. hourly precipitation (mm)
	$EI_{30\text{-monthly}}=(a+bP_{m24}^2)^2$	a = 1.316+0.00027H b = 0.004 H = elevation (m)

Table 4. Typical empirical rainfall energy (e) calculated for each time interval event's rainfall erosivity equations for calculating R.

Equation	Remarks
$e = 0.119 + 0.0873\log_{10}I$ ($I < 76$)	$e=0.29[1-0.72\exp(-0.05I)]$
$e = 0.283$ ($I > 76$)	$e=0.29[1-0.72\exp(-0.082I)]$

Knowledge of the relationship between rainfall intensity and kinetic energy in time and space is important for erosion prediction. However, between studies considerable variations exist in the reported shape and coefficients of this relationship. The critical reviews about studies of rainfall intensity and kinetic energy with a view to derive a general predictive equation of an exponential form is done by Dijka et al. (2002). Lee et al., (2011) also reported that a particular empirical equation for rainfall kinetic energy is needed to compute rainfall erosivity because rainfall erosivity will be produced differently if rainfall kinetic energy equation was different. In Table 4, typical empirical rainfall energy (e) calculated for each time interval event's rainfall erosivity equations for calculating R are shown. Dijka et al. (2002) concluded that standardised measurements are needed to evaluate rainfall intensity–kinetic energy relationships for such areas. Rose (1960) concluded that rainfall momentum is a slightly better predictor of soil detachment than kinetic energy, while Hudson (1971) indicted that momentum and kinetic energy for natural rainfall exhibit very similar relationships with intensity.

Discussion

The evaluation of R factor for various areas shows that on average per area there are more than two erosive rainfall events per year at each area. Considering the finding of Wischmeier (1962) that the R factor used to determine the average annual soil loss by erosion must involve the cumulative effect not only of the storms with maximal R but also of the other, medium-intensity rains satisfying the criteria determined. However, the results obtained according to the variant soil loss should be regarded as more indicative. Therefore, it is necessary to reassess the value of the R factor recommended hitherto for the practical application of RUSLE, depending on the criteria used for selection of the erosive rain events. These revised values of the standard R factor should be corresponded more closely with the values specified area. The values of R factor and the average precipitation sums over the specified season (June to August) or the average annual precipitation sums may not found to be statistically significant.

Therefore, the revised R factor values should be proposed as constitutive standards for the whole country. This change will result in more efficient conservation practices and will lead in future to better protection of soil from erosion.

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