EARTH SURFACE PROCESSES AND LANDFORMS, VOL 14, 509–515 (1989)

A CONTRIBUTION TO THE DEVELOPMENT OF AN EROSIVITY INDEX ADAPTED TO THE PREDICTION OF EROSION IN BELGIUM

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Received 30 May 1988
Revised 30 November 1988

ABSTRACT

In the Universal Soil Loss Equation, only rains in excess of, or equal to, 12·7 mm are taken into account and their intensity is represented by the maximum intensity reached over a 30 minute period. In Belgium, erosion recorded on experimental plots displays closest correlation to rainfall if a value superior or equal to 8 mm and a maximum intensity over 15 minutes are considered. Moreover the highest correlation is obtained by using the rainfall energy calculation formula put forward by Bollinne *et al.* (1984). The differences between the correlation coefficients are however not statistically significant and consequently the results point only to general trends. The suggested modification of the USLE is probably the result of the different nature of the precipitation in Belgium as compared with the U.S.A.

KEY WORDS Erosion USLE Erosivity Belgium

INTRODUCTION—THE PROBLEM

The Universal Soil Loss Equation (USLE) proposed by Wischmeier and Smith (1960, 1962, 1965) for North America has been applied without modification to various other climatic environments. There are grounds for questioning whether this equation ought not to be adapted for application in regions where the nature of precipitation differs from that of North America. The present article attempts to identify those elements which need to be introduced in formulating the erosion index best suited to the climate of coastal Western Europe below 200 m elevation and more specifically that of northern Belgium where the investigation was conducted.

Firstly it must be borne in mind that the erosivity index as defined by Wischmeier and Smith (1960) is the product of the value of two rainstorm characteristics: total kinetic energy of the storm times its maximum 30 minute intensity ($E.I$) divided by 100. This index represents the combined effect of splash and runoff. It should be noted that the kinetic energy of rainfall is the sum of kinetic energies of the pluviophases of which it is composed; each pluviophase is a period of rainfall during which the intensity can be considered constant. The energy of a pluviophase is a function of the rainfall intensity and is expressed by the formula $E = 89 \log I + 210$ (in metric tons m.cm^{-1} rainfall. ha^{-1}) (Laurant and Bollinne, 1978). To obtain the erosivity of the pluviophase, E must be multiplied by height in cm of the amount of rain of the pluviophase. The erosivity of a rain is therefore the sum of the erosivity of the n pluviophases which it comprises and can be expressed (in metric units):

$$R = E.I = 10^{-2} \sum_{i=1}^{i=n} (89 \log I + 210) . h . I_{\max_{30}}.$$

0197-9337/89/060509-07$05.00

This formula was determined empirically and is thus not necessarily the best; objective arguments moreover lead us to suppose that it ought to be modified The first of these is that the correlation coefficient obtained from a comparison of these results with measurements of erosion and the characteristics of the rainfall, only reaches 0 63 whereas in the U S A , the aforementioned authors quote a correlation equivalent of 0·9 (Bollinne, 1982) These correlations obtained in the U S A are the result of the compilation of seasonal data; identical treatment was not possible in Belgium owing to insufficient data Although the amount of data handled in Belgium is limited (33 observations spread over six years), the significant difference in the correlation is such that one might surmise that a more suitable formula could be found A second argument lies in the fact pointed out by Laurant and Bollinne (1978) that it is surprising that the American erosivity index applied in Belgium, notably at Uccle, yields values of the same order as the lowest figures calculated in the U S A. However measurements of erosion provide results which are very significantly higher than 11 t/ha years, higher limit admitted in the U S A

Let us review at this stage the various modifications which could be made to the erosivity formula

The rainfall values taken into consideration

It is possible to take into account rainfall below 12·7 mm (1/2 inch) which is the limit for Wischmeier and Smith (1960). It must also be borne in mind that these American researchers consider that a period of 6 hours with less than 1·27 mm (1/20 inch) of precipitation terminates a rain.

Bollinne *et al.* (1979) have shown moreover that the erosivity of rains of less than 12·7 mm was not insignificant; not at Uccle where it goes as high as 39 per cent of the total erosion, nor at Florenne (35 per cent), St-Hubert (26 per cent), or Spa (25 per cent) Bollinne (1983) has consequently made a provisional calculation of the erosivity for rains equal or above 1 mm However it is not proven that this threshold is the best possible

The maximum intensity used in the equation

The maximum intensity over 30 minutes which applies in the USLE could be replaced by the maximum intensity during a different period (10 minutes for example) As stated by Bollinne *et al.* (1984), in Belgium rains are generally of low intensity and the infrequent intense rains often do not last 30 minutes.

The rain energy calculation

The rain energy calculated from the intensity, perhaps expresses inadequately the effect of the less intense rains we experience in Belgium.

Within the framework of research into a more suitable formula, an investigation into the size of the raindrops in Middle Belgium was carried out (Bollinne *et al.*, 1984). It let to the proposal of another formula for the calculation of the energy of rainfall, namely

$$E = 126 + 57I$$

It is necessary to establish whether this formula is in fact an improvement for the climatic conditions of Belgium on that of Wischmeier and Smith (1960).

METHODOLOGY

General procedure

A solution to all these questions cannot come from anywhere other than a comparison between calculated erosion and actual erosion measured on the experimental plots. This is what is presented here. We shall compare the correlation coefficients obtained between erosion measurements taken at Sauveniere, Gembloux (Belgium), and the erosion index calculated using Wischmeier's formula (1960) on the one hand, and the Bollinne *et al.* (1984) formula on the other, for maximum intensities measured not just for 30 minutes, but for 10, 15, 20, 25, and 40 minutes and rainfall levels above or equal to 1, 2, 4, 6, 8, and 10 mm. Thus our task consisted in producing 144 different regressions multiplied by the number of relationships tested: simple regressions of first and second degree with data entries at their true value or expressed as their logarithm. These multiple tests enable the parameters for the optimum relationships to be defined

Measurements of eroded sediments

Erosion measurements were recorded by one of our team (Bollinne, 1982) at Sauvenière, near Gembloux from 1974 to 1979 on 12 experimental plots measuring 22 13 m (length identical to the American ones) × 4 m on a hillslope of 6 5 per cent The substratum was composed of aeolian loess (mode close to 30 μm) over which a washed brown soil (orthic hapludalf) developed. Of these 12 plots, four were planted with wheat, four were planted with beet, and four were left bare to lie fallow. All of these crops were rotated annually The results obtained from three fallow plots are considered here, the fourth being linked to a limnigraph providing only the rate of runoff It is necessary to stress that erosion readings obtained for one plot often varied considerably in comparison with those from neighboring plots Accordingly only mean results from the three fallow plots will be used

In six years investigation we have only 33 erosion readings It was quite impossible to sample and measure the sediments transported after each rainfall. Therefore erosion measurements were taken with variable intervals. For example in the year of exceptional drought 1976, only one result was recorded for the period from 2 2 76 to 30.9.76.

Measurement of splash

During the same period 1974–1979, in the immediate proximity to the soil loss plots, readings of the amount of earth displaced by splash were taken The splash captors used are in the form of circular funnels with a surface diameter of 52 mm which collect, on an unputrescible filter, the particles which reach it (Bollinne, 1975, 1980, 1982). The quantity of accumulated material is determined by weight In view of the great variability in results, 10 such captors were set up simultaneously Only the mean of the results—with obviously erroneous data being discarded—was taken into consideration Splash is expressed in t ha^{-1} (with the basis of calculation being the weight of earth collected and the catchment surfaces area of the instrument).

The nature of precipitation

The Sauvenière Experimental Station had two rain gauges installed which recorded the characteristics of the precipitation falling on the plots The interpretation of the pluviogrammes and their division into pluviophases was undertaken with the aid of a digitizer linked to a PC and programmed in such a way as to record 0 1 mm of precipitation and to allow a time of 1 minute The calculation of *EI* for each intensity threshold and for variable levels of rainfall was subsequently also carried out by computer The calculations were made using the USLE formula and also the Bollinne *et al* formula (1984).

THE RELATIONSHIP STUDIED

Figure 1 provides an example of a linear correlation obtained by the Bollinne *et al.* equation (1984) for rains in excess of, or equal to, 8 mm with a 15 minute intensity threshold. The equation for the regression is given below the figure as well as the correlation coefficient ($r = 0.71$) which features the degree of accuracy of the relationship between the calculated data and the observed data In the present article we are restricting our research to establishing the relationship which provides the highest correlation coefficient We have tried out simple linear relationships (Figure 1) and polynomial degree equations Although the latter give a better fit, they produce a curve on which a point is reached above which the erosion level falls with increasing precipitation Since this feature of the curve does not acceptably describe the physical phenomenon the use of polynomial degree equations was not considered appropriate.

We further tested relationships taking into account either true values or logarithmic values of erosion, splash, and the erosive factor The accuracy is significantly inferior to those obtained using the true values.

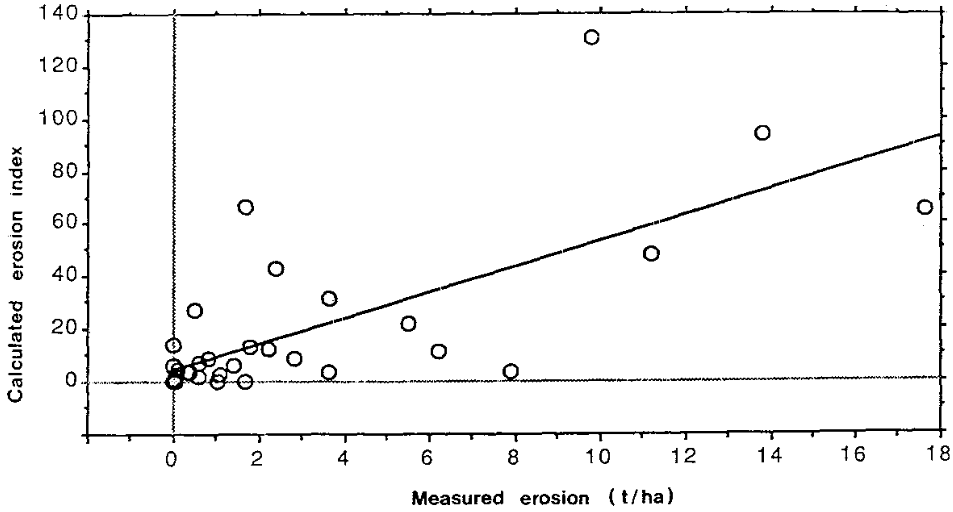

Figure 1 Relation between the values of measured erosion (X: tons ha^{-1}) and the erosivity index values (y) calculated using the formula of Bollinne *et al* (1984) (correlation coefficient $R=0.71$)

THE RESULTS

The results presented in Figure 1 do not show a homogeneous set of values. The statistical evaluation is therefore uncertain. To be totally objective we did not discard any of the collected data even though this would have given a better statistical result. It would have been possible for example to discard the highest measurement in Figure 1, following Schweitmann (1986) who thought better not to consider storms with a probability lower than 1 per 30 years.

The difference between the coefficients of correlation are not significant according to the equality test given by the formula

$$Z=1/2\ln\left(\frac{1+r}{1-r}\right)$$

Accordingly, the comments below point only to general trends.

Tables I to IV give the correlation coefficients obtained when establishing the regressions linking splash and erosion as measured in the Sauvenière plots over six years with the erosive factor values obtained by Bollinne *et al.* formula (1984) and that of Wischmeier and Smith (1960)

1. The relationship between the erosivity index and splash is better than that between the erosive factor and erosion. This outcome is not surprising since the phenomenon of splash is more immediately linked with the characteristics of rainfall than is runoff. Furthermore it must be remembered that the splash observations are the mean results of 10 captors, whereas erosion was measured from three bare fallow plots. Measurements of splash are therefore more accurate than measurements of erosion.
2. The equation proposed by Bolline *et al* (1984) yields a correlation that is a little better than that obtained using Wischmeier's formula.
3. The correlation coefficients are at their best, both in the case of the Bollinne *et al* (1984) and the Wischmeier and Smith equation (1960) when a maximum intensity over 15 minutes is employed in preference to the 30 minutes of the universal soil loss equation.

Table I. Correlation coefficients obtained for first degree equation bringing together the values of *measured erosion* and the erosivity index values calculated with the formula of Bollinne *et al.* (1984)

		Lower limit in mm of the water level reading for individual rains in the calculation of *EI*					
		1	2	4	6	8	10
Reference duration (minutes) in the calculation of the maximum intensity	10	0·68	0·68	0·69	0·70	0·70	0·68
	15	0·69	0·69	0·69	0·70	0·71	0·68
	20	0·67	0·68	0·68	0·69	0·70	0·67
	25	0·66	0·66	0·67	0·68	0·68	0·66
	30	0·65	0·66	0·66	0·67	0·68	0·65
	40	0·64	0·65	0·65	0·66	0·67	0·65

Table II. Correlation coefficients obtained for first degree equation bringing together the values of *measured erosion* and the erosivity index values calculated with the formula of Wischmeier and Smith (1960)

		Lower limit in mm of the water level reading for individual rains in the calculation of *EI*					
		1	2	4	6	8	10
Reference duration (minutes) in the calculation of the maximum intensity	10	0·64	0·64	0·64	0·65	0·67	0·64
	15	0·65	0·65	0·66	0·67	0·68	0·66
	20	0·64	0·64	0·65	0·66	0·67	0·63
	25	0·64	0·64	0·63	0·64	0·65	0·63
	30	0·61	0·61	0·62	0·63	0·65	0·63
	40	0·59	0·59	0·62	0·61	0·62	0·61

Table III. Correlation coefficients obtained for first degree equation bringing together the values of *measured splash* and the erosivity index values calculated with the formula of Bollinne *et al.* (1984)

		Lower limit in mm of the water level reading for individual rains in the calculation of *EI*					
		1	2	4	6	8	10
Reference duration (minutes) in the calculation of the maximum intensity	10	0·80	0·80	0·80	0·80	0·80	0·79
	15	0·80	0·80	0·80	0·81	0·81	0·79
	20	0·79	0·79	0·79	0·79	0·80	0·78
	25	0·78	0·78	0·78	0·78	0·78	0·77
	30	0·77	0·77	0·77	0·78	0·78	0·76
	40	0·77	0·77	0·77	0·77	0·77	0·77

Table IV. Correlation coefficients obtained for first degree equation bringing together the values of *measured splash* and the erosivity index values calculated with the formula of Wischmeier and Smith (1960)

		Lower limit in mm of the water level reading for individual rains in the calculation of *EI*					
		1	2	4	6	8	10
Reference duration (minutes) in the calculation of the maximum intensity	10	0·75	0·75	0·75	0·74	0·75	0·73
	15	0·75	0·75	0·75	0·76	0·75	0·74
	20	0·74	0·74	0·74	0·75	0·75	0·71
	25	0·73	0·74	0·73	0·73	0·73	0·71
	30	0·72	0·72	0·71	0·72	0·72	0·70
	40	0·70	0·70	0·71	0·71	0·71	0·68

4. Finally, correlation coefficients are at their best in the case of rainfall in excess of, or equal to, 8 mm When lower rates of rainfall are involved, the erosion index is less closely correlated to field observations both in the case of erosion and splash.

INTERPRETATION

The measurements obtained from experimental plots in Middle Belgium seem to indicate:

1. That the erosivity formula proposed by Bollinne *et al.* (1984) gives better results for Belgium than that of Wischmeier but the coefficients of correlation are not significantly different in either case.
2. That in applying this formula, one should consider only rainfall equal to, or in excess of, 8 mm and a maximum intensity of 15 minutes

It would appear prudent to stress that these results are the product of only 33 different observation periods and that the calculations of correlation coefficients are thus based only on treatment of these 33 pieces of data However, the correlation coefficients are all above the value 0·35 (the minimum value significantly different from zero for $n=33$) and are therefore significantly different from zero to the level 0·95 It is also open to question whether these results obtained on bare, fallow plots with a gradient of 6·5 per cent and lying on aeolian loess can be applied to all plots in Northern Belgium. The nature of the soil, the slope, and the vegetation cover might very well, depending on circumstances, alter the position of the threshold established in the present research. For example, as a consequence of a difference in soil permeability, runoff might systematically appear more rapidly, and this would convey a greater influence on lighter rainfall Nonetheless, the present work indicates that in the calculation of the erosive factor in Belgium it is pointless to consider rainfall as light as 1 mm. Calculations of the erosive factor will thereby be greatly facilitated, in view of the considerable reduction in the number of rains taken into account.

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