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THE DISTRIBUTION OF KINETIC ENERGY OF RAINFALL IN THE SUGAR BELT OF NATAL

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Abstract

Soil losses in areas planted to sugarcane in Natal are a cause for concern. In the absence of experimental data, one method of estimating soil loss is to use the Universal Soil Loss Equation. A variable in this equation is the rainfall erosivity factor which contains a term for the kinetic energy of rainfall. This paper describes the derivation of kinetic energies from rainfall records, and presents a map of the mean annual distribution of rainfall kinetic energy for the sugar belt of Natal.

Introduction

Soil losses in areas planted to sugarcane in Natal are a cause of concern to conservation-minded farmers and to the researchers at the SASA Experiment Station at Mount Edgecombe. Monitoring of soil losses from plots has commenced at Mount Edgecombe, but it will be several years before the results can be comprehensively evaluated in terms of the soil loss model that has been selected, namely, the Universal Soil Loss Equation, USLE.

In the USLE, soil loss is related to the interaction between intrinsic soil properties and cropping and management factors, the slope length (a measure of contour spacing), the slope steepness and a rainfall erosivity factor. The rainfall erosivity factor involves a term for the kinetic energy of rainfall (E), which Wischmeier and Smith (1958),[4] the originators of the USLE in 1965,[5] expressed as:

$$E = 11{,}90 + 8{,}73 \log I \ (\mathrm{J\ m^{-2} mm^{-1}\ rainfall})$$

where

I = the rainfall intensity in mm h^{-1}.

In this paper the derivation of rainfall kinetic energies from records of rainfall intensity is described. Generalized energy: rainfall equations are established for each month of the year, and from these equations mean annual distributions of E have been determined and mapped for the Natal sugar belt.

The Data

For selected meteorological stations in South Africa the SA Weather Bureau tabulates for each month the number of occurrences of 15-minute rainfall amounts at different class intervals of rainfall. The intervals used for these rainfall amounts are:

0,1 - 1,0 mm
1,1 - 2,0 mm
2,1 - 4,0 mm

and then progressing at 2,0 mm intervals to 44,0 mm in 15 minutes. These data are extracted manually from the autographic raingauge charts. From these rainfall amounts mean rainfall intensities may be calculated and by using the data for the number of occurrences of these amounts, together with the E : I equation, monthly estimates of rainfall energy may be made. Twenty-seven years' data of the type described above were available for Durban and were used in this analysis of rainfall energy.

A second source of rainfall energy data can be derived from charts of autographic raingauges, but using clock-error-corrected digitized records. For each pair of digitized points from a recorder chart, energy may be estimated from the rainfall intensity (ie the rainfall difference/incremental time). Energy is then integrated for individual storms and summed for monthly totals. Nine years of such records were available from Cedara for this purpose.

Method of analysis

The Weather Bureau data for Durban were first punched onto computer cards. This was followed by an error check, whereby a computed monthly rainfall (determined by the summation of the products of occurrences and amounts for each rainfall class) was compared with the given rainfall for the month. By this check punching errors were revealed as were gross human errors which could possibly have occurred in the manual extractions and tabulations at the Weather Bureau. Obvious errors could then be corrected; where a degree of uncertainty remained as to the source or type of error, the data were discarded.

For each 15-minute rainfall class, R_{15}, the kinetic energy of rainfall could then be expressed as:

$$E = 11{,}90 + 8{,}73 \log_{10} (R_{15} * 4.) * R_{15} * OCC$$

where

OCC = the number of occurrences of 15-minute rainfall amounts in that class. Summation of energies for all rainfall classes yielded the total monthly estimate of rainfall kinetic energy. For the 23 rainfall classes given by the Weather Bureau the median values of each class were assumed to be representative of the rainfall amount. Thus, for example, an occurrence of 15-minute rainfall in the 10,1 - 12,0 mm class was assigned the amount of 11,0 mm. Exceptions were, however, made in the lowest three rainfall classes, where an analysis of digitized records from Mount Edgecombe and Cedara showed distinctly positively skewed distributions of 15-minute rainfall amounts, such that most typical (modal) amounts of rainfall were found to be:

0,33 mm in class 0,1 - 1,0 mm at the coast
0,35 mm in class 0,1 - 1,0 mm in the interior
1,35 mm in class 1,1 - 2,0 mm at the coast
1,40 mm in class 1,1 - 2,0 mm in the interior
and 2,90 mm in class 2,1 - 3,0 mm at the coast.

Soil loss equations such as the USLE (Wischmeier and Smith, 1965)[5] involve long-term average annual or seasonal values of E as one of several inputs. Where records of energy are of short duration or extend over different periods of time, as is the case for the two stations used in this analysis, significant biases in the soil loss equations may therefore be introduced by the E factor. Wischmeier (1976)[3] stresses the use of long-term averages to smooth out inter-annual E variations and suggests for the eastern United States of America, for example, the use of at least 22 years of records to overcome effects of "22 year weather cycles" there. Climatic fluctuations with different periodicities may exist in South Africa (Tyson, 1978).[2] Furthermore, rainfall kinetic energy regimes show distinct evidence of seasonality (Schulze, 1978)[1] depending on whether rainfall is associated primarily with local thunderstorms, with sub-continental or coastal low pressure systems or with frontal activity. To overcome the problems of periodicity and seasonality, correlations were therefore sought between E and monthly rainfall which could then be used to obtain more realistic estimates of long-term means of E. Simple linear rather than more complex regressions of E versus rainfall were found to yield the best overall results.

In order to extrapolate energy estimates from the two selected stations to other areas of the sugar belt each of the stations was assigned a "domain" for which it was assumed that the respective E: rainfall equations would describe the rainfall energy regime adequately. For the sugar growing areas of Natal a coastal region was separated, in terms of the rainfall climate, from an inland region. The coastal region was defined by the 500 m contour with the inclusion of any areas above 500 m which were within 20 km from the coast. For each of the two regions suitably distributed stations (160 in all) with long-term rainfall records of over 20 years were selected. The appropriate E : R equations were then applied to the long-term records of the 160 stations to yield estimates of monthly, seasonal and annual rainfall energies.

Results

Energy: Rainfall Relationships

The E : R relationships for the individual months of the year are shown for Durban, representatives of the coastal stations, and Cedara, taken to represent the inland stations, in Fig. 1. Correlation coefficients between energy and rainfall were all significant at the 0,01 level and were generally of the order of r = 0,85 to 0,95.

Considerable differences in the lines of regression between months as well as between the two stations may be seen in Fig. 1. For Cedara the high incidence of thunderstorm-derived rainfall accounts for the steep slopes in the regressions for the summer months when compared with the flatter slopes for the winter months, when most precipitation is derived from low intensity frontal rainfall. The coastal station Durban generally displays flatter E : R slopes than Cedara as well as a less clearly defined seasonal distribution of high energy rains. The E : R relationship for Durban is characterized by relatively large negative intercepts which again indicates a high incidence of low energy rainfall (Fig. 1). These differences are important in establishing the seasonal and annual distributions of rainfall energy in the Natal sugar belt.

The distribution of Rainfall Kinetic Energy in the Natal Sugar Belt

By applying the above equations to long-term mean monthly rainfall data from the 160 selected stations mean monthly

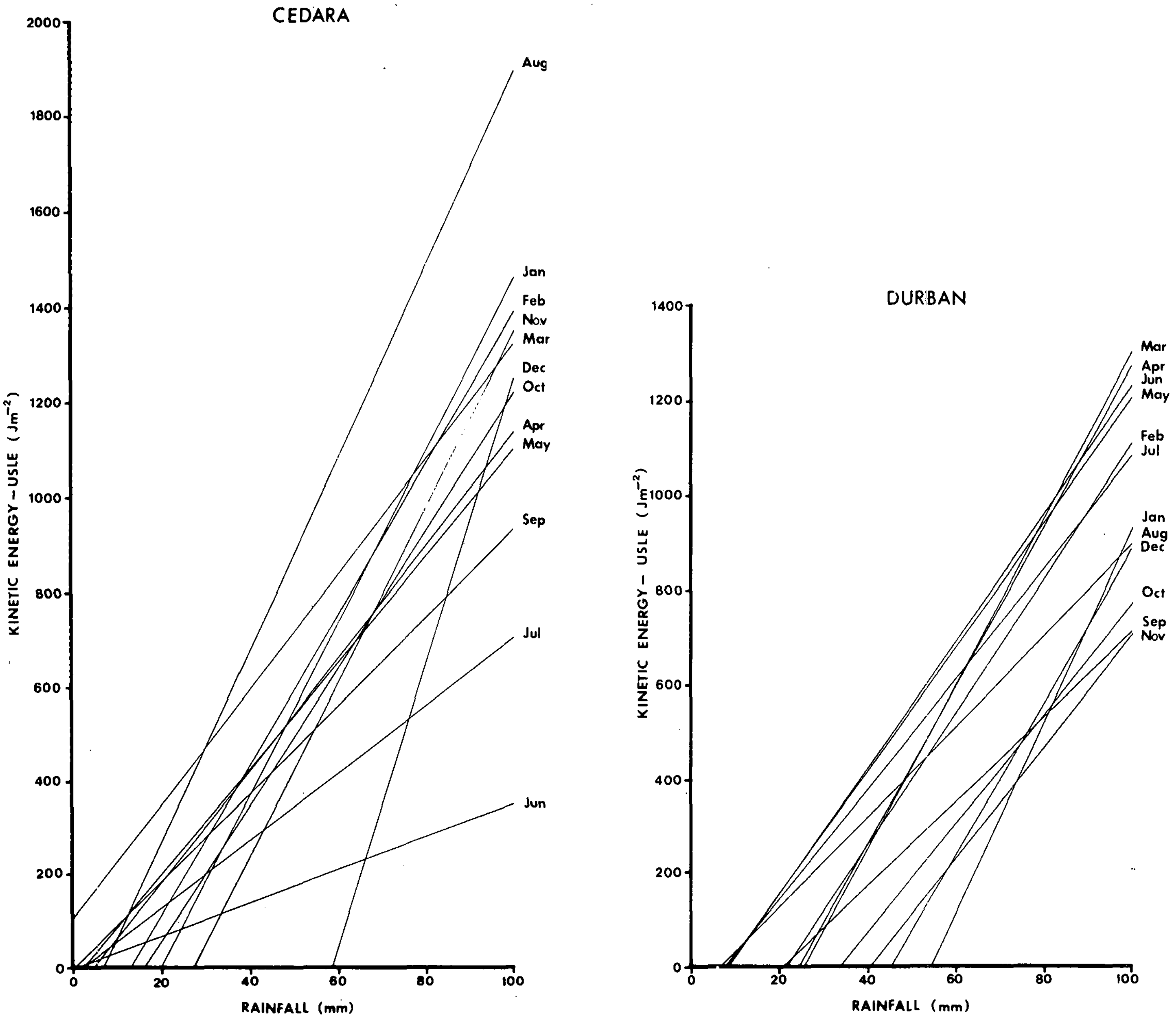

FIGURE 1 Kinetic energy: rainfall relationships at Cedara and Durban.

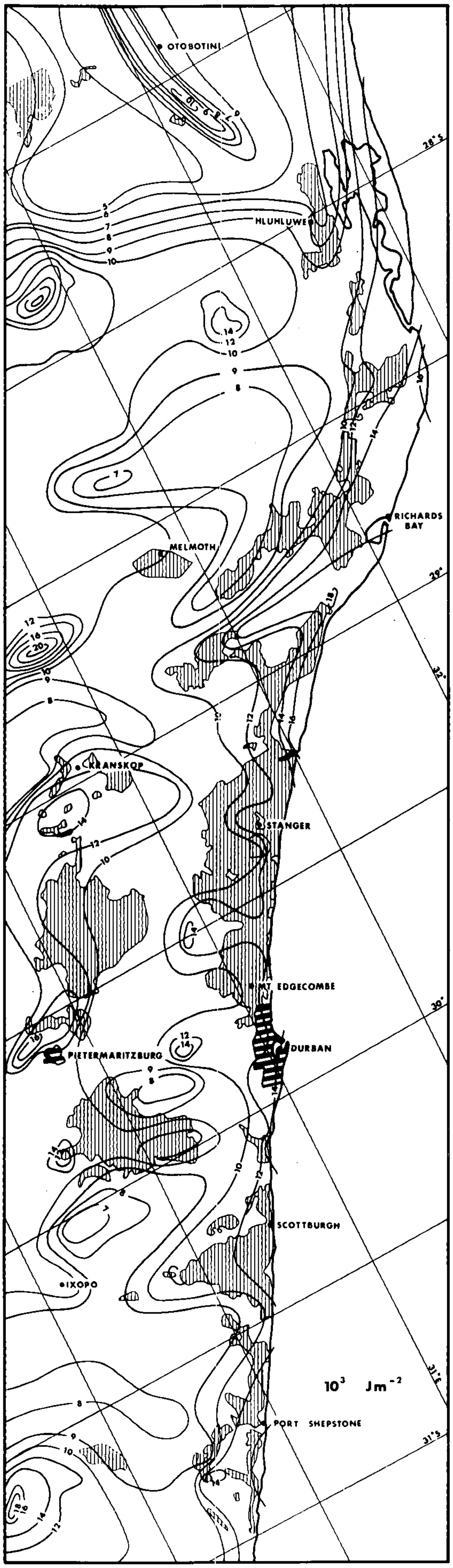

FIGURE 2 Distribution of the mean annual kinetic values.

rainfall energy was determined and the annual distribution of E was then plotted (Fig. 2).

Examination of Fig. 2 shows that within the sugar belt of Natal there is apparently a vast range of mean annual rainfall energies, from less than 4 000 J m^{-2} to more than 20 000 J m^{-2}. Low rainfall energies are experienced in the northern areas on the Pongola valley west of the Lebombo Range and on parts of the Makatini flats. Apart from nodes of high energies associated with isolated high altitude areas (for example, Ngome), one zone of rainfall energies in excess of 10 000 J m^{-2} per annum stretches along the coast from St. Lucia to Port Edward. Particularly high soil losses as a result of high rainfall energies may be expected in the Richard's Bay-Ngoye area where mean annual energies exceed 14 000 J m^{-2}. A second zone of relatively high rainfall energies exists in the sugar growing areas of the Natal Midlands along the Richmond - Pietermaritzburg - Greytown - Kranskop axis. This inland zone experiences 80–85% of its total rainfall energy in the summer months October to March, which are characterized by sometimes severe thunderstorms. The coastal zone, on the other hand, can expect 20–30% of its total annual rainfall energy in the winter months from April to September.

Conclusion

With the measurement of soil in the sugar belt only in its initial stages, research emphasis is at present focussing on the application and adaptation of physically based soil loss models such as the USLE. The USLE is known to be very sensitive to the rainfall energy input. With little knowledge of the magnitudes and the pattern of rainfall energy in the Natal sugar belt, a first attempt has therefore been made to derive regional rainfall energy equations and to map distributions of E.

Much research in this vital field of applied hydrology is required in South Africa. More base stations are needed, as are longer records, a digitized rather than manually extracted data base and information on highest 30-minute rainfall intensities of storms to determine the USLE's erosivity factor. It is to be hoped, however, that the distributions of kinetic energy of rainfall of the sugar belt provided here will serve a useful purpose as a source of one input variable in a model delimiting zones of high or low soil losses.

Acknowledgements

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