Drop Characteristics and Erosivity of Rainfall in Southwestern Nigeria

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Abstract

Raindrop samples were colleted over a 2–year period (1977–1979) at the University of Ife Campus (Southwestern Nigeria) for analysis of raindrop size–Kinetic energy–intensity relationships and estimation of the erosive potential of rainstorms. Similar relationships presently used in the predictive universal soil loss equation were substantially different and under estimated the energy load and erosive potential of rainstorms of the study area at rainfall intensities of 120mm/hr and less. Higher rainfall erosivity, compared to temperate and subtropical regions, was attributed to greater proportion of large raindrop sizes (3mm and more) and high rainfall intensities.

Introduction

The study of raindrop characteristics continues to be of considerably interest particularly in the evaluation of rainfall erosivity and ultimate development of erosion control measures because of the wellknown role of raindrops as the primary source of energy for water erosion. Both the mass and velocity components of the kinetic energy of rain are related to the size of raindrops. Various indices for estimating the erosive potential of rainfall have thus been developed from certain rainfall parameters that influence soil erosion (Wishchmeier et al, 1958, Hudson, 1971, Elwell and Stocking, 1973, Lal, 1976). Perhaps the most widely used erosivity index is the EI_{30} index (Wischmeier et al, 1958) defined as the product of the total kinetic energy and maximum 30–minutes intensity of rainfall times 10^{-2} and presently used in the Universal Soil Loss Equation developed in temperate U.S. by Wischmeier and associates (Wischmeier and Smith, 1958).

The kinetic energy component of the EI_{30} index is computed from equation (1) derived by Wischmeier and Smith, (1958) from drop size–intensity relationship published by Laws and Parsons (1943) and data on terminal velocities of water drops by Gunn and Kinzer (1949):

$$KE = 210.3 + 89 \log 10^{I} \qquad (1)$$

where KE is the kinetic energy (metric–ton meter per ha per cm of rain) and I is intensity (cm/hr). Drop size–intensity relationships established in the temperate region may deviate under a different climatic and agro–ecological setting of the tropics, thus resulting in low efficiency of the EI_{30} index or the Universal Soil Loss Equation. The scanty available information on rainfall erosivity have suggested low predictability of EI_{30} in tropical and subtropical regions (Hudson, 1971; Ahmad and Breckner, 1974, Lal, 1976). In this study, drop size distribution and kinetic energy were determined in relation to intensity of rainfall at Ife, Southwestern Nigeria. Erosivity of rainfall was also estimated using the kinetic energy–intensity relationship.

Materials and Methods

Raindrop samples were collected during a 2–year period (October 1977 – September 1979) at the University of Ife main campus (Nigeria) using the flour pellet method. EI_{30} erosivity index was computed according to Wischmeier and Smith (1958) for all rainstorms during this period from the record of an automatic tilting siphon rainguage.

The flour pellet method of measuring raindrop sizes consists of exposing containers of freshly sieved flour to rain for a few seconds. Dough balls or pellets that form harden up upon air drying and are further dried to constant weight in an oven at 105°C. The weights of the raindrops can be computed from the corresponding pellet weights by calibrating the flour.

Wheat flour (Golden Penny brand) used in this study was calibrated by allowing distilled water drops of varying pre–determined sizes (formed by using different sizes of glass tubes and hypodermic needles) to fall from some height into a 2.5–cm chick layer of freshly sifted (<210 u) uncompacted flour. The pellets for each class of water drops were air dried and separated from the flour, oven dried to constant weight (after 24 hours) at 105°C and weighed. The ratio (mass ratio) of the weight of water drop to that of pellet formed from it was computed for each drop size class as shown in Fig. 1.

Heights of fall of water drops of one meter and 12 meters were selected to facilitate the determination of the effect of drop velocity on flour calibration. The 12–meter height was the second floor of a building and measurements were taken in the open on a humid January (1978) morning when evaporation of falling water drops was minimal. Drop velocity had no significant effect on flour calibration.

Freshly sifted calibrated flour contained in 10–cm diameter dishes were then used to sample natural raindrops by exposing them to rainfall for a period of 4 seconds. Sampling was always around the rainguage and at 4 to 5 times during rainfall to ensure coverage of a wide range of intensities. The time of sampling, synchronized with clock time of the rainguage was always noted to facilitate the relation of raindrop size distribution to rainfall intensities recorded by the rainguage. After sampling the pellets were processed in the same manner as for flour calibration. Oven dry pellets of each sample were separated into size classes by a set of standard sieves with mesh sizes ranging from 0.02 to 4 mm. Pellets in each size class were weighed and counted after discarding malformed ones that formed from more than one raindrop. The average raindrop weight (mg) of drops in each size class was calculated from the relation:

$$M = p \times r \qquad (2)$$

where p is the average pellet weight in mg for the size class and r is the mass ratio corresponding to p in the calibration curve. The average diameter (D) was then computed by the equation:

$$D = (6m \pi r^{-1})^{1/3} \qquad (3)$$

Cumulative volumes, computed as the percentages of total mass of the sample in each size class, were related graphically as in Fig. 2 to the average diameter of each class. The median drop size, D_{50} taken as the drop size at 50% volume of the cumulative curve was then related to the intensity of rainfall prevailing at time of sampling.

The kinetic energy of raindrops was calculated using raindrop size distributions obtained in this study and terminal velocity values reported by Gunn and Kinzer (1949).

Results and Discussion

Annual rainfall at Ife for the period of study averaged 1620mm (Fig. 3A) distributed bimodally with a short dry spell (from late July to early August) that separates the first cropping season from the second. Most rains occurred in thunderstorms with 55% of the storms having intensities over 25mm/hr and 24% having intensities over 75,,/hr (Fig. 3B). The rainstorms are considered intense compared to temperate storms that rarely exceed 75mm/hr in intensity. An earlier erosion study by Wilkinson (1975) and results on raindrop size distribution (Fig. 4) are also indicative of the aggressiveness of rainstorms of the study area.

Average raindrop diameter increased with rainfall intensities up to 75mm/hr, then decreased at higher rainfall intensities up to 125mm/hr (Fig. 4). Drop sizes at intensities above 125mm/hr fluctuated but did not increase appreciably with increasing rainfall intensity to justify a cyclic drop size–intensity relationship as suggested by Carter et al (1974). McGregor and Mutchler (1977) reported a similar noncyclic relationship for rains in Holly Springs, Mississippi (U.S.) Median raindrop sizes were greater than 3.5mm at rainfall intensities above 125mm/hr. Results were substantially different from those reported for temperate regions by Laws and Persons (1943). Bean and Wells (1953), and for subtropical Rhodesia by Hudson (1963). The relationship between raindrop size, D_{50} and rainfall intensity, I was described by the following equation with a correlation coefficient of 0.94:

$$D_{50} = 1.231 + 0.6941 - 0.1321 \quad + 0.0051 \quad - 0.000091 \qquad (4)$$

This equation clearly indicates greater proportion of large raindrops for given rainfall intensities compared to values reported for the temperate and subtropical regions. Drop size distribution was similar to that reported for Ibadan (Aina et al. 1977), 75km west of Ife. Predominant raindrop size was 3.5mm at rainfall intensities above 40mm/hr.

Mean annual erosivity factor, R was 560 (metric) units which is considered high compared to values elsewhere in West Africa (Roose, 1973, Aina et al, 1977), Southeast U.S. (Wischmeier and Smith, 1958) and Ife (Wilkinson, 1975). Actual erosive potential of rainfall was apparently underestimated by equation (1). The kinetic energy–intensity relationship at Ife was of the form:

$$KE = 20.9 + 5.511 - 0.791 \quad + 0.0431 \quad - 0.00081 \qquad (5)$$

where KE is kinetic energy (Joules M^{-2} mm^{-1}) and I is rainfall intensity (cm/hr). Annual erosivity factor based on equation (5) averaged 705 (metric) units.

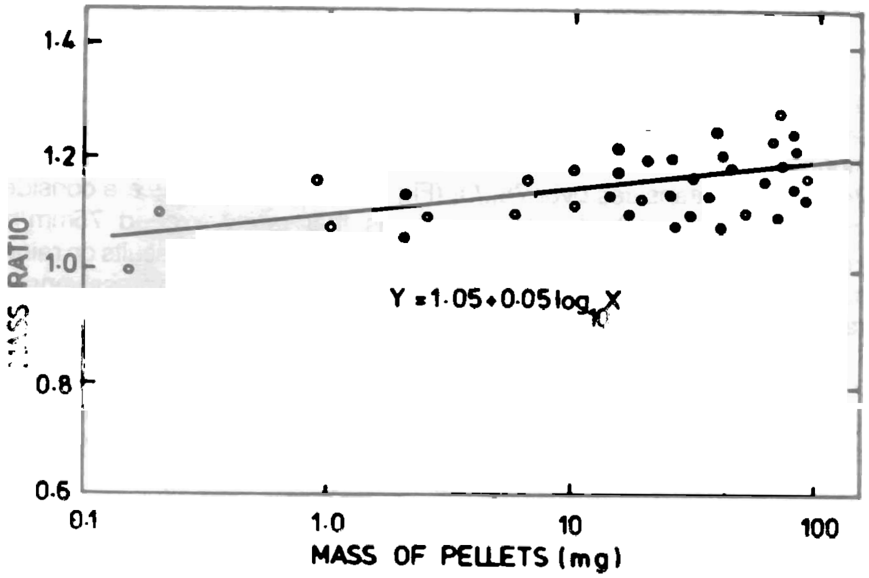

Fig. 1 Flour calibration curve relating mass of pellet to mass of water drop.

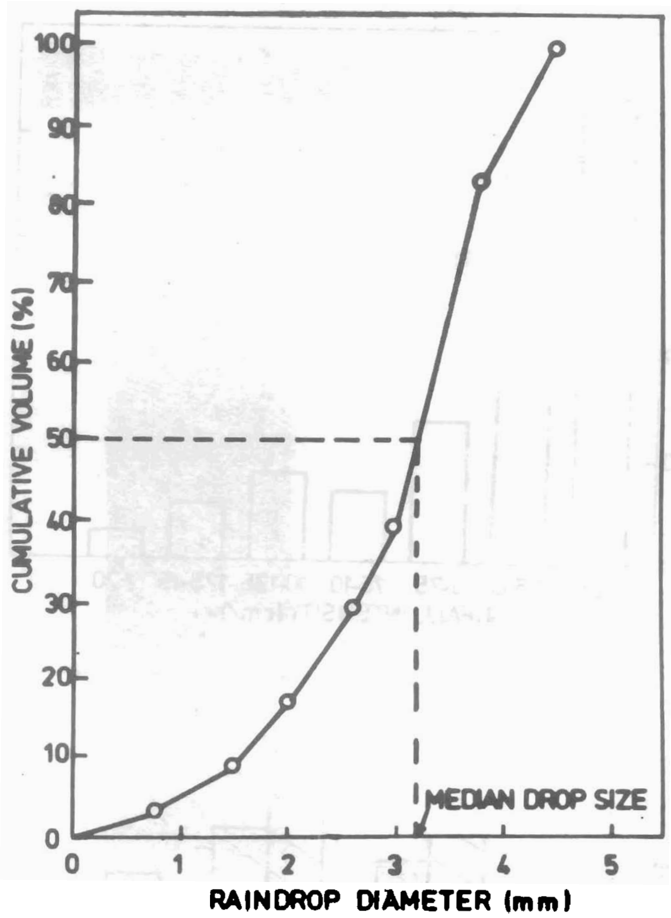

Fig. 2. Cumulative frequency curve for median drop size determination.

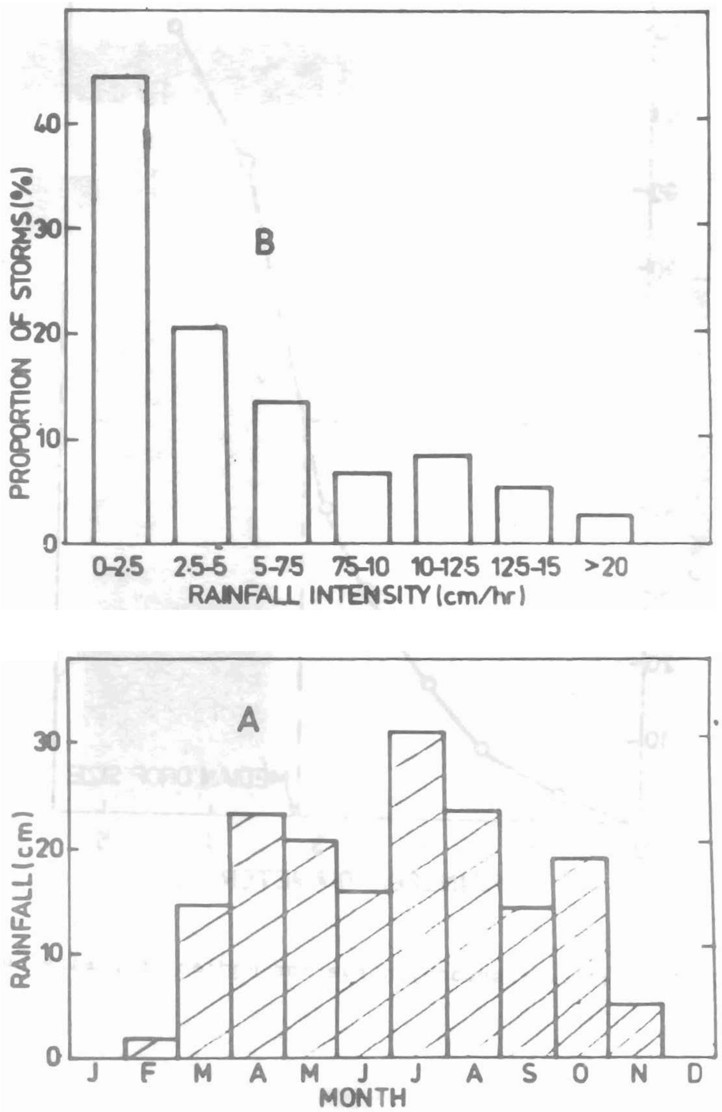

Fig 3. Annual rainfall distribution (A) and Proportion of rainfall at Ife during 2 years (1977-1979) for different intensity intervals (B)

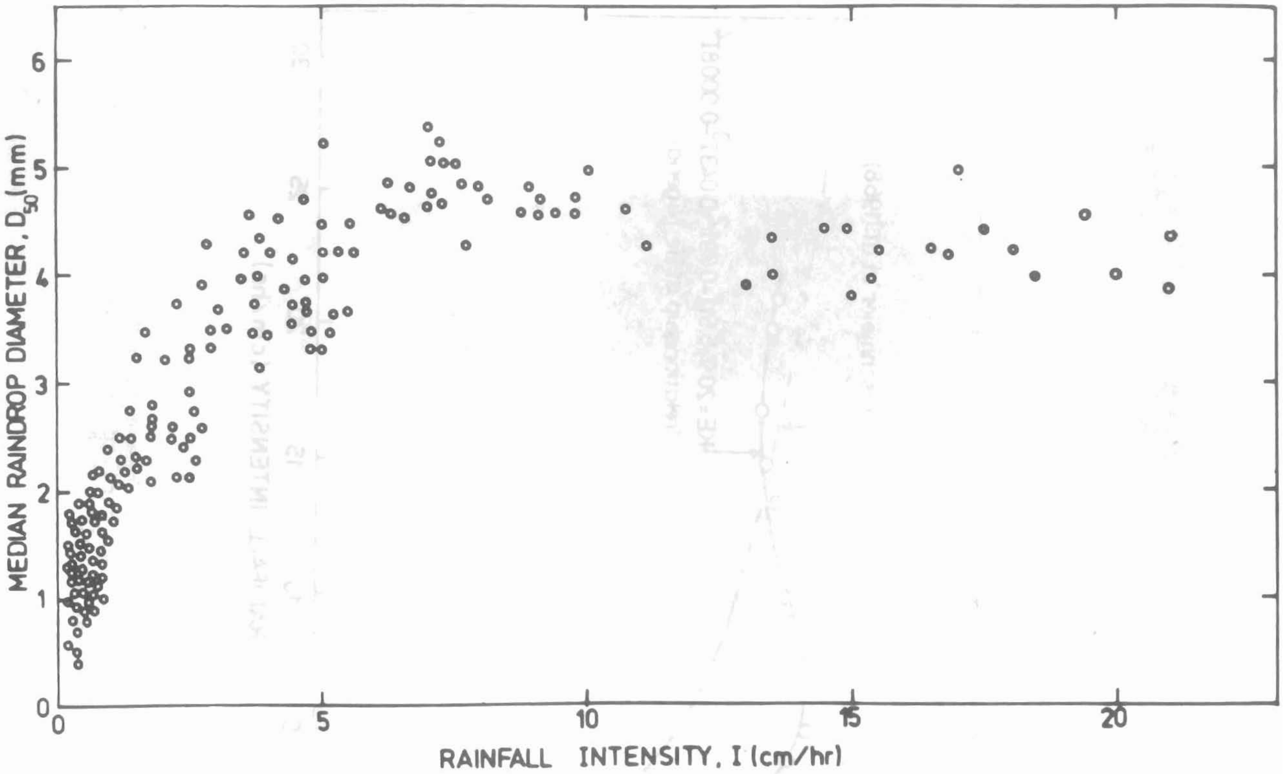

Fig. 4. Relationship of median raindrop size and rainfall intensity at Ife.

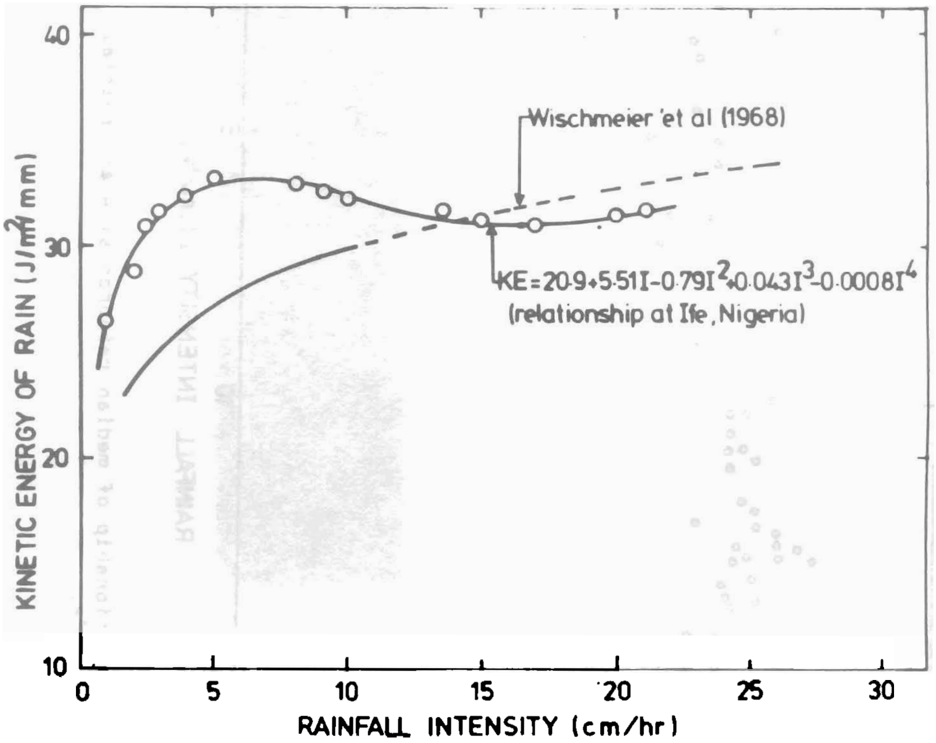

Fig. 5. Relationship of Kinetic energy and rainfall intensity at Ife compared with that derived from Washington D.C (U.S) data by Wischmeier et al, (1958).

Compared to equation (5) the kinetic energy–intensity relationship presently used in the universal soil loss equation underestimated the kinetic energy of rainstorms of the study area at rainfall intensities ranging from about 10 to 120mm/hr. Since more than 50% of rainstorms fell in this range of intensities (as indicated in Fig. 3 B), the energy load of total rainfall would be much higher compared to values in temperate (Fig. 5) and subtropical regions. Kowal and Kassam (1976) reported for a 1091–mm total rainfall at Samaru (Northern Nigeria) a total kinetic energy load of about 36,000Jm^{-2} which is twice as much as reported by Elwell and Stocking (1973) for subtropical Rhodesia. The greater kinetic energy load of rainstorms at Ife was apparently due to the greater proportion of large drops (3mm and more in diameter) and high intensities.

Conclusions

Rainstorms at Ife were highly erosive. The high energy load was due to high proportion of large drops and high rainfall intensities. The actual erosiveness of rainfall was underestimated by the drop size–kinetic energy–intensity relationships presently used in the universal soil loss equation (Wischmeier and Smith, (1958). Because of the possibility to further increase in kinetic energy of rain due to strong winds distinctive of tropical rainstorms (Ahmad and Breckner, 1974), the need arises for the direct determination of the kinetic energy of tropical rainstorm.

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