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Relative Efficiencies of Erosivity Indices in Soil Loss Prediction in South Eastern Nigeria

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Abstract: Rainfall data from 3 representative locations in southeastern Nigeria were used to evaluate and establish 3 rainfall erosivity: The product of rainfall amount and the maximum 7.5 min intensity (Aim); the product of rainfall kinetic energy and maximum 7.5 min intensity (E_kI_m) and the product of rainfall kinetic energy and AI_m (E_kAI_m). These indices were applied in the Universal Soil Loss Equation (USLE), to estimate soil loss in the 3 locations. The predicted soil losses were compared with the measured soil losses. The result of the study shows that (E_kI_m) has a higher efficiency of predicting soil loss in the region and thus this can be used to estimate soil loss in southeastern Nigeria.

Key words: Erosivity indices, erodibility, soil loss, kinetic energy, USLE, Nigeria

INTRODUCTION

Alarming rates of soil erosion have been reported various parts of Nigeria. In southeastern Nigeria, records on soil erosion for the last two hundred yeas exist (Niger Techno, 1975).

In many developed countries of the world, soil loss can readily be predicted under any postulated conditions, using existing soil loss models. This is yet to be the case in Nigeria where such models and there parameters have not been established. Consequently, soil loss in the country can now only be satisfactorily estimated from experimental soil loss plots. Various empirical erosivity models or indices have been postulated in Nigeria which is a very vital factor in soil loss prediction. There is therefore the need to establish the index that predicts soil loss with greater efficiency than others under any given condition in the country.

In southern Nigeria which includes the southeastern Nigeria, independent studies (Lal, 1976; Obi, 1982; Madubuike *et al*., 1990; Nwaukwa, 1991; Udosen, 2000) aimed at establishing rainfall erosivity indices applicable to specific locations of the region have been carried out. Lal (1976) found the product of rainfall amount and the maximum 7.5 min intensity (AI_m) the best estimator of soil loss in Ibadan. He also suggested the inclusion of the kinetic energy factor E_k to AI_m (i.e., E_kAI_m) as an improved rainfall index for his location. This is because of the importance of kinetic energy of typical tropical rainfall. Obi (1982) proposed the product of kinetic energy and the maximum 7.5 min intensity (E_kI_m) for the Nsukka location while Madubuike *et al*. (1990) recommended the rainfall amount (A); the rainfall kinetic energy (E_k), the product of kinetic energy and rainfall amount (E_kA) and the product of kinetic energy and the maximum 7.5 min intensity E_kl_m, in that order for the Owerri location. The maximum 7.5 min intensity rainfall is used because characteristically, tropical rainfall has very high intensity but short durations which may cause serious harm to the soil if they are neglected.

To obtain the point rainfall intensity, the recording rain gauge charts were analyzed by breaking the rainfall events into 7.5 min intervals (Wischmeier and Smith, 1965; Lal, 1976) as shown in Table 1. The maximum 7.5 min intensity for the rainfall event recorded in Table 1 is 96 mm hr^{-1}. The rainfall kinetic energy (E_k) was evaluated using Eq. 1 developed by Kowal and Kasam (1976) under tropical conditions and is given by

$$E_k=(41.4Pa - 120) \times 10^{-2} \quad (1)$$

Where Pa = Rainfall amount (mm)
E_k = Kinetic energy (MJ ha^{-1})

Three erosivity indices were evaluated and applied in the study to estimate soil loss, viz:

- The product of rainfall amount and maximum 7.5 min intensity as established by Lal (1976) and designated Al_m.
- The product of kinetic energy and the maximum 7.5 min intensity as proposed by Obi (1982) and designated E_kl_m.
- The product of kinetic energy and Lal's Al_m as further suggested by Lal (1976) and designated E_kAl_m.

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Table 1: Recording rain gauge charts

Time interval (min)	Rainfall amount (mm)	Rainfall intensity (mm hr^{-1})
7.5	10	80
7.5	3	24
7.5	12	96
7.5	10	80
7.5	4	32
7.5	3	34

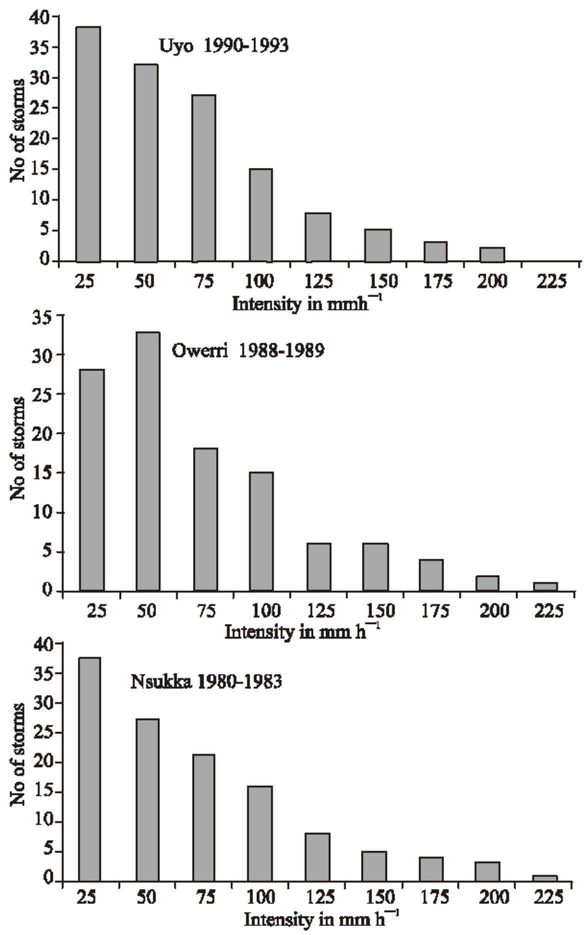

Fig. 1: Frequency distribution of rainfall intensity classes in locations in south-eastren Nigeria

These indices were evaluated for and applied in the Universal Soil Loss Equation, USLE. Wischmeier (1976) Eq. 2 (when the erodibility,topography,crop management and conservation practice factors are each assumed to be unity), to estimate soil loss in each of the three locations. The estimated and measured soil losses were compared and statistically analyzed. The universal soil loss equation used to estimated soil loss under any given condition is given by

$$A = 2.24\ RKLSCP \quad (2)$$

Where

A = Average annual soil loss in kg ha^{-1} (metric ton ha^{-1})

R = Rainfall and runoff erosivity index

K = Soil erodibility factor, which is the average soil loss in t ha^{-1} per unit of erosion index

LS = Topographic factor

C = Cropping management factor, which is the ratio of soil loss for given conditions to soil loss from cultivated continuous fallow

P = Conservation practice factor.

RESULTS

The annual distribution of rainfall for the years available data for the three locations under study as well as the computed 7.5 min rainfall intensities have been detailed by Nwaukwa (1991) and Udosen (2000). The highest individual rainstorm total amounts for the periods under review were 181, 82 and 113 m for Uyo, Nsukka and Owerri locations, respectively while the highest individual maximum 7.5 min intensities were 175, 145 and 269 mm hr^{-1}, respectively.

Figure 1 shows the frequency distribution of rainfall intensity classes for various locations studied. In Uyo, Nsukka and Owerri 68, 64 and 73% of the storms respectively were of intensities greater than 256 cm hr^{-1}; a threshold intensity above which rainstorms become erosive (Hudson, 1965). The percentages of storms exceeding 75 cm hr^{-1} intensity were 25, 21 and 28, respectively in the above locations.

Table 2 shows part of the estimated soil loss using the evaluated rainfall erosivity indices while Table 3 shows the average correlation between the (estimated soil loss) and the measured soil loss for the different locations. Table 4 details the result of the statistical analysis carried out on the estimated and measured soil losses.

DISCUSSION

Soil loss estimates using the index E_kl_m were most consistent for all years at all locations while the E_kAl_m estimates showed the largest disparity when compared to the other estimates in Nsukka and Owerri. In Uyo, the E_kAI_m estimates were generally closer to the other estimates particularly those of the AI_m index. Nevertheless, the disparity between the E_kAI_m estimated and the other estimates was still substantial (Table 3). The results of the statistical analysis shown in Table 3 and 4 confirm the above assertion.

Table 2: Estimated soil loss by various indices at the different locations

Year	Location erosivity index	Uyo estimated soil lose ($g\ m^{-2}$)	Year	Locations erosivity index	Nsukka estimated soil lose ($g\ m^{-2}$)	Year	Locations erosivity index	Nsukka estimated soil lose ($g\ m^{-2}$)
1972	AI_m	530.6	1980	AI_m	580.8	1988	AI_m	2965.0
		540.5			589.6			2103.9
	E_kI_m	171.8		EkI_m	198.2			7408.0
		157.5			191.5		E_kI_m	1706.1
	E_kAI_m	2289.2		E_kAI_m	3270.5			1429.1
		2327.6			2563.3			1536.8
		2229.6					E_kAI_m	48733.3
1973	AI_m	1358.4	1981	AI_m	708			28221.9
		1290.3			583.7			13310.4
		294.4		E_kI_m	236.5	1989	AI_m	664.6
	E_kI_m	477			195.6			1080.3
		473.2		E_kAI_m	4433.9			1894.3
		450.5			3715.7		E_kI_m	389.2
	E_kA_{Im}	9111.3	1982	AI_m	599			401.3
		8199.7			528			388.0
1974	AI_m	1115.2		E_kI_m	263.2		E_kAI_m	6090.6
		1070.9			243.2			7361.6
		955		E_kAI_m	4042.8			14299.9
					5132.2			
	E_kI_m	364.1	1983	AI_m	612.5			
		382.4			614.4			
		334.4		E_kI_m	197.9			
	E_kAI_m	6621.3			208.3			
		6287.2		E_kAI_m	2612.1			
					3332.5			

Table 3: Average correlation between estimated and measured soil loss for the various locations

Location	Erosivity index	Average correlation coefficient
Uyo	AI_m	0.744
	E_kI_m	0.750
	E_kAI_m	0.764
Nsukka	AI_m	0.606
	E_kI_m	0.821
	E_kAI_m	0.712
Owerri	AI_m	0.750
	E_kI_m	0.869
	E_kAI_m	0.717

Table 4: Analysis of variance of the performance of the three rainfall erosivity indices

Location	Erosivity index	F_{cal}	F_{tab}	Significances 5%	Level 1%
Uyo	AI_m	-5.280	0.234	*	**
	E_kI_m	-0.068	3.630	ns	
	E_kAI_m	0.183	2.750	ns	
Nsukka	AI_m	0.310	0.584	ns	
	E_kI_m	0.280	0.640	ns	
	E_kAI_m	5.410	0.280	*	**
Owerri	AI_m	-5.650	0.625	*	**
	E_kI_m	0.040	0.847	ns	**
	E_kAI_m	1.670	0.960	*	*

Key:*Significant at the indicated level, **Highly significant at the indicated level, F_{cal}=Mean square treatment(observed), Mean square error, F_{tab}=Mean square treatment(expected), Mean square error, When F_{tab} is greater than F_{cal} + the effect is non-significant

The correlation between estimated and measured soil loss (Table 3) shows that the index E_kI_m is the best estimator in all the locations under review. The much lower correlation obtained for AI_m estimates for the Uyo and Nsukka locations strengthens the generally accepted importance of kinetic energy factor in establishing the erosivity index parameter for computing soil loss.

The performance of the AI_m index was significant at the 5 and 1% levels of confidence in Owerri and Uyo while that of the E_kAI_m index was significant at the same levels in Nsukka and Owerri (Table 4). The two indices AI_m and E_kAI_m are therefore unacceptable for the Owerri location. The E_kAI_m index however, performed relatively well in Uyo when compared to the other indices (average r = 0.764 and Table 4) which validates Lal' (1976) suggestion that the inclusion of the energy factor to AI_m could produce an improved index E_kAI_m for the location.

The performance of E_kI_m was however not significant at the 5% and 1% levels in all the locations. Consequently, this rainfall index (E_kI_m) is shown to have greater efficiency in soil loss prediction than the others (AI_m and E_kAI_m) studied and therefore should and therefore should be regionally applicable index that can be used to estimate soil loss in the three locations studied.

CONCLUSION

The study confirms, once again, the generally accepted importance of the rainfall energy factor in establishing the erosivity index parameter required for computing soil loss. Although the rainfall indices which include the rainfall amount factor (AI_m and E_kAI_m) performed reasonably well only in specific locations, the product of kinetic energy and the maximum 7.5 min intensity is shown to be the regionally applicable rainfall index that can be used in estimating soil loss in south eastern Nigeria.

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