



Discussion paper

Development of isoerodent maps for Nigeria from daily rainfall amount

F.K. Salako

Department of Soil Science and Land Management, University of Agriculture, PMB 2240, Abeokuta, Nigeria

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ABSTRACT

In this study, rainfall erosivity factor, R , of the Revised Universal Soil Loss Equation (RUSLE) was estimated from daily rainfall amounts of the coastal, humid forest, savanna, semi-arid and arid zones of Nigeria using data from 17 locations, which spanned 10–33 years. Two power law equations were applied to compute the products of kinetic energy, E , and (i) maximum 30-minute intensity, I_{30} (El_{30}), and (ii) maximum 15-minute intensity, I_{15} (El_{15}). The indices were used to develop monthly and annual isoerodent maps. Mean monthly El_{30} ranged from 600 to 3200 MJ mm ha⁻¹ h⁻¹ whereas the annual values ranged from 3000 to 27,000 MJ mm ha⁻¹ h⁻¹ from the arid to the coastal zones. The El_{15} index was 1.7 times greater than the El_{30} . Trends of rainfall erosivity in the derived, southern Guinea and northern Guinea savannas or wet savannas were erratic and less predictable from the trends of rainfall amount, unlike in the coastal, humid forest, semi-arid and arid zones. Extrapolation of data for soil conservation planning did not appear feasible in the wet savannas. Monthly values of erosivity presented are recommended for conservation plans during the cropping seasons in the various agroecological zones. The El_{15} index is recommended for both monthly (seasonal) and annual soil loss computations because short-term intensities reveal rainfall erosivity better in the tropics.

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1. Introduction

It is desirable to translate values of rainfall erosivity factor, R , in the Revised Universal Soil Loss Equation (RUSLE) to isoerodent maps for different countries or regions (Wischmeier and Smith, 1978; Renard et al., 1997). This is not often achieved in many developing nations due to non-availability of basic data. This limitation has, however, been met by the estimation of R from rainfall amounts (Arnoldus, 1977; Obi and Salako, 1995; Salako et al., 1995; Yu, 1998; Hoyos et al., 2005; Salako, 2006, 2008). Such estimates have also been used to draw isoerodent maps, mainly with annual values (Arnoldus, 1977; Roose, 1977; Salako, 1988; Renard and Freimund, 1994; Odoro-Afriyie, 1996; da Silva, 2004), which are quite not amenable to calculation of seasonal erosivity. Based on the review by Hoyos et al. (2005), annual rainfall erosivity from the arid/semi-arid tropics to the very humid tropics ranges from about 250–33,481 MJ mm ha⁻¹ h⁻¹. Mannaerts and Gabriels (2000) reported annual erosivity of 90–3506 MJ mm ha⁻¹ h⁻¹ for semi-arid Cape Verde.

It has been shown by various authors (e.g., Richardson et al., 1983; Elseisenbeer et al., 1993; Yu and Rosewell, 1996; Salako, 2006, 2008) that a power law relationship exists between R factor and rainfall

amount. It is important that for this relationship to be applicable in a location, constants should be developed locally. Furthermore, relationships which allow R to be calculated from daily rainfall amounts allow temporal changes in erosivity at short intervals to be understood and considered in soil conservation planning (Renard et al., 1997). Salako (2006, 2008) showed that the coefficients of determination obtained for the relationship of R with rainfall amount were better, using daily rather than annual values for the sub-humid and humid (coastal) zones of Nigeria. Therefore, this study was carried out (i) to quantify rainfall erosivity and its spatial distribution in Nigeria using daily rainfall amounts and (ii) to develop isoerodent maps for Nigeria based on the estimated R factor.

2. Materials and methods

2.1. Locations and data collection

The study was carried out with daily rainfall amount data collected from 17 meteorological stations covering all the ecological zones of Nigeria (Table 1). Nigeria is located between latitudes 4°N and 14°N and longitudes 2° 2' and 14° 30' East. The data from ordinary rain gauges which covered different periods (10–33 years) were collected from the Nigerian Meteorological Services, Oshodi, Lagos and the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Daily rainfall data from 1998 to 2005 for Onne (Port-Harcourt), and 2000–2005 for Ibadan have now been included to extend the periods covered by Salako (2006, 2008). There were no missing daily

E-mail addresses: kfsalako@yahoo.ie, kolawolesalako@hotmail.com.

Table 1Geographic description of locations[#], years covered by daily rainfall amount data and their ecological zones in Nigeria.

Location	Latitude (°N)	Longitude (°E)	Elevation (m)	Years covered	Ecological classification	Annual rainfall (mm) [‡]
Onne	4.717	7.175	441	1977–2005	Coastal/humid forest	2417b
Calabar	4.950	8.317	99	1988–2001	Coastal/humid forest	2935a
Lagos	6.453	3.396	35	1988–2001	Coastal/humid forest	1556c
Ijebu-Ode	6.817	3.933	70	1988–2005	Humid forest	1625c
Abeokuta	7.150	3.350	67	1991–2005	Sub-humid/DS	1179defg
Ibadan	7.388	3.896	293	1973–2005	Sub-humid/DS	1296d
Lokoja	7.800	6.733	145	1988–2005	Sub-humid/SGS	1231de
Ilorin	8.500	4.550	290	1988–2001	Sub-humid/SGS	1111efg
Saki	8.667	3.383	457	1988–2001	Sub-humid/SGS	1128efg
Minna*	9.617	6.550	302	1991–2001	Sub-humid/SGS	1273de
Jos	9.917	8.900	1198	1988–2001	Sub-humid/NGS	1202def
Bauchi**	10.317	9.833	610	1988–2005	Sub-humid/NGS	1031g
Kaduna	10.523	7.317	634	1988–2005	Sub-humid/NGS	1212def
Yelwa	10.530	4.450	244	1988–2001	Sub-humid/NGS	1066fg
Kano	11.996	8.517	479	1990–2005	Semi-arid/SSS	786h
Sokoto	12.917	5.150	309	1988–2005	Semi-arid/SSS	670h
Nguru**	12.967	10.467	341	1988–2005	Arid/SSS	386i

[#]Geographic description obtained from the website, <http://www.heavens-above.com> and the database of Nigerian Meteorological station, Oshodi, Lagos, Nigeria.

*1999 data excluded.

**1989 data excluded.

***1996 and 2003 data excluded.

DS Derived savanna.

SGS — southern Guinea savanna.

NGS — northern Guinea savanna.

SSS — Sudano-Sahelian savanna.

[‡]Ranking is based on Duncan's multiple range test: Similar letters for different locations indicate that there were no statistical differences in annual rainfall amounts while different letters indicate significant differences.

rainfall data for the years considered in the analysis for each location (Table 1). Furthermore, the mean annual and monthly rainfall amounts agree with long-term means (Akintola, 1986) of the locations. Therefore, the daily rainfall data used in this study were considered reliable. In spite of this, the exclusion of the data for one or two years in 3 locations (Table 1) was due to improper data collection.

2.2. Estimation of rainfall erosivity from daily rainfall amount

The data were used to calculate erosivity indices using the power law relationships developed by Salako (2006, 2008) (Table 2), as follows:

$$\text{Erosivity Index} = aA^b \quad (1)$$

where Erosivity Index is either $El_{30}\text{-WS}$ ($\text{MJ mm ha}^{-1} \text{h}^{-1}$), product of rainfall kinetic energy, E , based on Wischmeier and Smith (1978) equation (Renard et al., 1997), and maximum 30-minute intensity, I_{30} or $El_{15}\text{-BF}$ ($\text{MJ mm ha}^{-1} \text{h}^{-1}$), product of rainfall kinetic energy, E , based on Brown and Foster (1987) equation (Renard et al., 1997), and maximum 15-minute intensity, I_{15} . A is daily rainfall amount (mm), a

and b are parameters with different values for the sub-humid and humid regions (Table 2).

The reliability of the data used for the development of the equations was discussed by Salako (2006, 2008). The erosivity indices of the coastal (CZ) and humid forest (HZ) zones were estimated with parameters developed for the humid zones whereas the indices for the sub-humid (wet savannas), semi-arid and arid zones were estimated with parameters developed for the sub-humid zones (Tables 1 and 2). The CZ and HZ have amount-driven erosivity whereas the derived (DS), southern Guinea (SGS), northern Guinea (NGS) or wet savannas; Sudano-Sahelian (SSS) or dry savanna and the arid zone have intensity-driven erosivity, based on the distinctions proposed by Salako (2006, 2008).

2.3. Data analysis and development of isoerodent maps

From the daily values, monthly and annual means of R and rainfall amount were compared for the different ecological zones using STATISTIX (Analytical Software, 1998) and Duncan's multiple range test (Steel and Torrie, 1981). Isoerodent maps of monthly and annual R were drawn using SURFER (Golden Software Inc., 2006) contour map option.

3. Results and discussion

3.1. Rainfall erosivity in relation to ecological zones and indices

The highest annual rainfall was obtained in Calabar (coastal zone) and the lowest was obtained in Nguru (arid zone) (Table 1). The wet savannas or the sub-humid zones did not have distinct differences. The overall means of annual $El_{30}\text{-WS}$ ($10,886 \text{ MJ mm ha}^{-1} \text{h}^{-1}$) and $El_{30}\text{-BF}$ ($13,509 \text{ MJ mm ha}^{-1} \text{h}^{-1}$) were similar. This confirms further that the Brown and Foster (1987) equation is a good substitute for Wischmeier and Smith (1978) equation, as suggested by Renard et al. (1997), and as reported by Salako (2008). It follows that the differences between $El_{30}\text{-WS}$ and $El_{15}\text{-BF}$ was a result of the difference between the intensity (I_{30} and I_{15}) components (Tables 2 and 3; Figs. 1–4). Therefore, each index is referred to as either El_{30} or El_{15}

Table 2Parameters for calculating rainfall erosivity indices from daily rainfall amount[§].

Rainfall erosivity index	Intercept, a	Slope, b	Coefficient of determination, r^2
<i>Sub-humid zone</i>			
$El_{30}\text{-WS}$ ($\text{MJ mm ha}^{-1} \text{h}^{-1}$)	0.66	1.74	0.86
$El_{15}\text{-BF}$ ($\text{MJ mm ha}^{-1} \text{h}^{-1}$)	0.579	1.940	0.86
<i>Humid zone</i>			
$El_{30}\text{-WS}$ ($\text{MJ mm ha}^{-1} \text{h}^{-1}$)	0.27	1.94	0.96
$El_{15}\text{-BF}$ ($\text{MJ mm ha}^{-1} \text{h}^{-1}$)	0.355	2.005	0.92

[§]Source: Salako (2006, 2008).

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