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Determination of Short Term Erosivity Index for Goronyo Dam, Sokoto State, Nigeria

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ABSTRACT: Rainfall erosivity, considering rainfall amount and intensity, is an important parameter for soil erosion risk assessment under future land use and climate change. The rainfall parameter that expresses the capacity to promote soil erosion is called rainfall erosivity (R), and is commonly represented by the indexes EI_{30} and KE>25.The evaluation indicated that by defining an erosive rainfall event as(a) rainfall ≥ 12.5 mm or (b) rainfall intensity > 6 mm per 15 minutes. The R factor of the station under studied at Goronyo Dam for year 1988 was 3670.3 J mm/M^2yr and that of year 1989 was 558.68 J mm/M^2 yr respectively. Therefore, the availability of a rainfall erosivity map is a key issue not only for soil erosion and landslide risk assessment but also for agricultural management practice, soil conservation and climate change.

Keywords: Erosion, rainfall, water, soil

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INTRODUCTION

Erosivity is a measure of the potential ability of soil, regolith, or other weathered material to be eroded by rain, wind, or surface runoff). Historically, the term erosivity was first associated with an *R*-factor (rainfall-runoff erosivity factor) in the Universal Soil Loss Equation (USLE). *R*-factor as used in the USLE and the revised USLE (RUSLE) relates to the mean annual sum of EI_{30} values. EI_{30} is the most commonly used rainfall erosivity index, where *E* is the total kinetic energy per unit area during a precipitation event (MJ·ha^{-1}) and I_{30} is its peak 30-min intensity (mm·ha^{-1}). Thus, erosivity of precipitation events is a function of their intensity and duration, and of the mass, diameter, and velocity of the raindrops. In principle, each detachment-transport system can be represented by an equation that has an erosivity term (Springer, 2016).

Rainfall-runoff erosivity factor (R). It is the average annual summation (EI) values in a normal year's rain. The erosion-index is a measure of the erosion force of specific rainfall. When other factors are constant, storm losses from rainfall are directly proportional to the product of the total kinetic energy of the storm (E) times its maximum 30-minute intensity (I). Storms less than 0.5 inches are not included in the erosivity computations because these storms generally add little to the total R value. R factors represent the average storm EI values over a 22-year record. Rainfall-runoff erosivity factor R is an indication of the two most important characteristics of a storm determining its erosivity: amount of rainfall and peak intensity sustained over an extended period. Though not enough record is available for the long term erosivity it was decided to compute the short term index.

The same thing is a case of the lack of a long time series mainly concerned regions with low rainfall erosivity such as Latvia, Finland and Estonia. These regions are also characterized by a very low internal variation, which led to the decision to include these data in the analysis. As the main objective of Panagos *et al.* (2015) was to create an R-factor map of Europe, it is more advantageous to have the maximum possible number of observations (in geographical and feature space) for the interpolation (even if this results in higher uncertainty)

than to have fewer stations available for interpolation. Moreover, the Gaussian Process Regression model smoothness estimation reduces the risk of short length time series by acting as data outliers (Rasmussen and Williams 2006).

The erosivity of rainfall varies greatly by location. The R factor in Michigan ranges from 75 to 135. Approximately 70 percent of the erosivity occurs in the months of May, June, July and August in Michigan (USDA 2016).

Soil erosion is a widespread land degradation problem in many parts of the world. On-site and off-site costs of soil erosion reach about 44 billion dollars in the United States (Pimentel *et al*., 1995), 4.2 billion dollars in Brazil (Hernani *et al*. 2002) and 45.5 billion dollars in the European Union (Telles *et al*., 2011). Assessing the risk of erosion, predicting erosion rates and designing and evaluating different soil protection strategies is an essential tool for selecting soil and watershed best management practices. Rainfall is the main climatic characteristic that influences soil erosion, given the extraordinary importance of soil detachment processes due to drop impact and runoff shear.

Among Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE) factors, the erosive capacity of rainfall is expressed as rainfall erosivity (R), commonly represented by the indices EI_{30} (Wischmeier and Smith, 1958) or KE>25 (Hudson,1973). On the other hand, some empirical equations can also estimate values of rainfall erosivity by using geographical coordinates or pluviometric records, such as annual and monthly rainfall averages (Silva, 2004; Hoyos, 2005; Aquino *et al*., 2008; Capolongo *et al*., 2008).

Rainfall erosivity is a term that is used to describe the potential for soil to be washed off from disturbed, de-vegetated areas and move with into surface waters during storms. It may also be defined as the potential ability of rain to cause the erosion. It is dependent upon the physical characteristics of rainfall, which include raindrop size, drop size distribution, kinetic energy, terminal velocity, etc. For a given soil condition, the potential of two storms can be compared quantitatively, regarding soil erosion to be caused by them. The power of overland runoff flow to erode soil material is partly a property of the rainfall, and partly of the soil surface. Rainfall erosivity is highly related to soil loss.

Increased rain erosivity indicates greater erosive capacity of the overland water flow. Soil erosion by running water occurs where the intensity and duration of rainstorms exceeds the capacity of the soil to infiltrate the rainfall. The potential for erosion is based on many factors which include including soil type, slope, and the energy or force of precipitation expected during the period of surface disturbance (Murti *et al.,* 1985).

The erosivity factor *R* for the USA was derived from a large quantity of data on precipitation. From these data it is possible to deduce that, keeping the factors other than rainfall constant, the soil loss from a cultivated field is directly proportionate to the following characteristics of a storm: the product of total kinetic energy of rainfall (*E*) and its peak 30-minute intensity (I_{30}):

$$R = E \times I_{30}/100 \qquad (1)$$

Where:
R – Rainfall erosivity factor (MJ/ha.cm/h)
I_{30} – peak 30-minute intensity of rainfall (cm/h)
E – total kinetic energy of rainfall (J/m²)

$$E = \sum_{i=1}^{n} Ei \qquad (2)$$

Ei– kinetic energy of the *i*-th segment of rainfall
(*n* – Number of rainfall segments)

$$Ei = (206 + 87\ log\ Isi) \times His \qquad (3)$$

where:

Isi – intensity of the *i*-th segment of rainfall (cm/h)
Hsi– rainfall amount in the *i*-th segment (cm).

The appearance of deep erosion furrows, also called rills, and the amount of accumulated sediment after unusually intensive rainfall events made researchers draw conclusions that significant erosion phenomena were connected with several storms only and were the function of peak intensities. However, according to Wischmeier (1959, 1962), more than 30-year measurements in many localities in the USA indicated that this conclusion does not hold well.

Data on the rainfall factor used to determine the average annual soil loss should involve the cumulative effect of both extraordinary rainfall events (intensive storms) and many rainfall events of medium-intensity. The average annual value of factor *R* is calculated from long-term records of precipitation, and it is the sum of the annual erosivity of particular storms, whilst not all events are considered; those of smaller precipitation sum than 0.5 inch, i.e.12.5 mm, separated from preceding and successive rainfall events by rainless periods longer than 6 h, are omitted if at least 0.25 inch (6.25 mm) of rain did not fall in the course of 15 min. Hence the rainfall erosivity factor *R* depends on the frequency of occurrence of rainfalls, and ontheir kinetic energy, intensity and amount.

The values of the *R* factor were processed statistically and presented in the form of isoerodent maps. For the Czech Republic, the average rainfall erosivity factor *R* = 20 MJ/ha.cm/h was calculated from a long-term series of rainfall observations for the Prague-Klementinum, Tábor of the Czech Hydrometeorological Institute (CHMI) (Janeček, 1992). Applying the newly processed long-term series of ombro graphic records from other stations of CHMI made it possible to analyze the method of *R* factor determination for the Czech Republic in more detail.

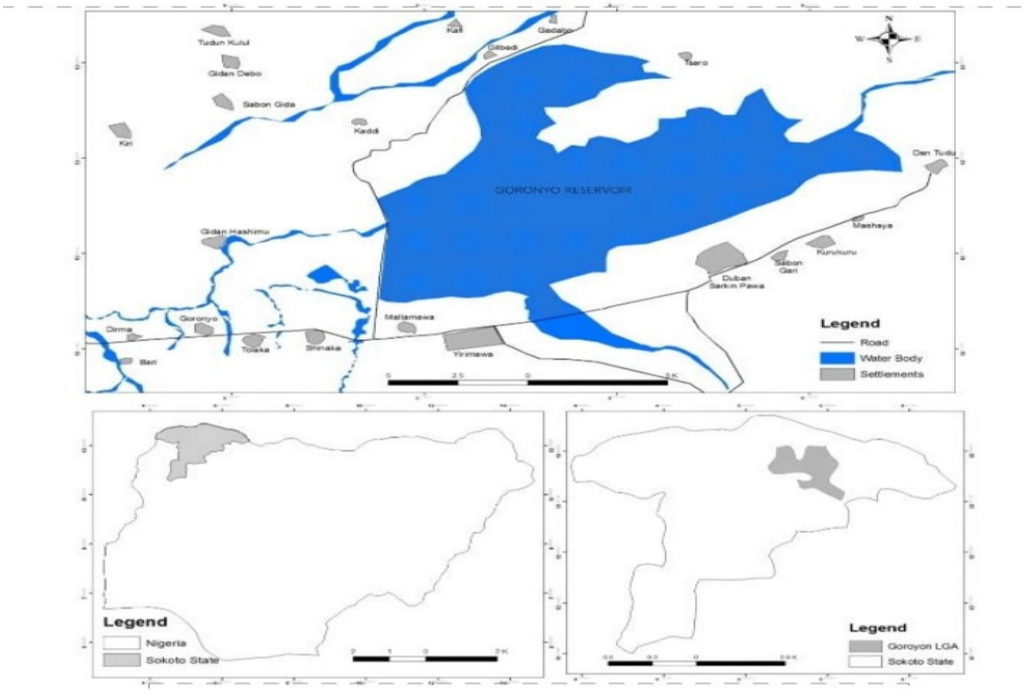

Figure 1: Map Showing the Study Area (Goronyon Dam).

The relation between rainfall and sediment yield is given by the rainfall erosivity, which quantifies the kinetic energy of raindrop impact and rate of associated surface runoff. As field measurements of the kinetic energy of rainfall are scarce both in space and time, numerous works have assessed the relationship between conventional rainfall characteristics and soil detachment e.g. Hudson (1971) for the USA and some regions in Africa, Arnoldus (1977) for Morocco (Meusburger *et al.,* 2012).

MATERIALS AND METHODS

Study area

Goronyo Dam is situated in the north between latitude 13^0 40'0"N to 13^0 44'0"N, in the east by longitude 5^0 14'0"E to 5^0 17'0"E. The dam has a length of about 20 km with a width of about 10 km and an area of about 200 km^2 and a storage capacity of 942 million cubic metres (Abubakar, et al., 2017). The study area is part of Sokoto – Rima basin, which has a total catchment area of about 193,000 km^2 (Figure 1). The climate in the area is semi tropical with a prolonged dry season from October to May and a short – wet season from end may to early October. The temperature in the region ranges from minimum of 20^0 C to maximum temperature of about 35^0 C. The rainfall in the area shows both spatial and temporal variations. The mean annual rainfall varies from 700 mm to 1,100 mm (Adeniyi, 1993).

Method

A computational algorithm was developed to identify all the erosive precipitations on each rainfall series. The erosive precipitations were taken as all rainfall with depth equal or higher than 10 mm or lower than 10 mm in depth, but with a 15 minute duration depth equal or higher than 6 mm (Wischmeier and Smith 1958, Wischmeier 1959. Before the calculation of EI30 (Wischmeier and Smith 1958) and KE>25 (Hudson 1973) indices, it was necessary to estimate the erosive precipitation kinetic energy (KE). KE values were computed individually by the equations proposed by Hudson method

$$KE = 29.8 - \left(\frac{127.5}{I}\right) \quad (4)$$

Where:

KE = kinetic energy, $MJ.ha^{-1}.mm^{-1}$; and
I = rainfall intensity, $mm.h^{-1.}$

Equations 4 were used to compute KE of all the erosive rainfall. Erosive rainfall with greater intensities were assumed to have a KE equal to 0.283 $MJ.ha^{-1}.mm^{-1}$, as long as the raindrop diameter does not rise up to rainfall intensities greater than this limit (Foster et al., 1981).
The EI_{30} parameter for each specific event was calculated as the product of total kinetic energy (KE)

Table 1: Rainfall Amount, Rainfall Intensity and Kinetic Energy.

Month	DATE	RAINFALL AMOUNT (mm)	DURATION (min)	RAINFALL INTENSITY (mm/hr)	KINETIC ENERGY (J/M^2/mm)	TOTAL KINETIC ENERGY J/M^2
	1/6/1988	45	7.1	380.30	29.465	1325.925
	8/6/1988	148	3.2	2776.74	29.754	4403.592
	22/6/1988	135	5.8	136.50	29.709	4010.715
	25/6/1988	30	7.9	227.84	29.240	877.212
JUNE	30/6/1988	180	65.6	164.64	29.026	5224.608
	8/7/1988	50	3	1000	29.673	1483.625
	11/7/1988	19	2.2	518.135	29.554	561.524
	13/7/1988	25	12.3	121.951	28.755	718.863
	14/7/1988	135	20.2	400.986	29.482	3980.071
	24/7/1988	88	44	120.001	28.738	2528.900
	27/7/1988	45	16.2	166.667	29.035	1306.575
JULY	30/7/1988	180	8.2	1317.070	29.703	5346.574
	2/8/1988	180	89.6	120.540	29.742	5173.615
	5/8/1988	45	17	158.540	28.997	1304.878
	6/8/1988	90	1.8	3000.000	29.758	2678.175
AUGUST	7/8/1988	55	2	1650.017	29.723	1634.765
						44,043.240
	12/6/1989	19	5	228.009	29.241	555.579
	18/6/1989	11	3	220.000	29.220	321.420
	21/6/1989	60	8	450.113	29.517	1771.020
	23/6/1989	15	2	450.045	29.517	442.755
JUNE	29/6/1989	48	21	137.143	28.870	1385.774
	6/7/1989	20	5.6	214.293	29.205	584.100
	9/7/1989	30	6.8	264.714	29.318	879.550
	10/7/1989	5	3.4	88.230	28.355	141.775
	11/7/1989	7	1.2	350.000	29.436	206.050
	15/7/1989	33	17.4	113.793	28.680	946.424
	17/7/1989	125	24.8	302.422	29.378	3672.301
	19/7/1989	6	0.4	886.656	29.656	177.937
JULY	29/7/1989	211	13.1	966.427	29.668	6259.963
	1/8/1989	45	13	206.110	29.181	1313.163
	2/8/1989	61	32	112.507	28.667	1748.669
	8/8/1989	86	32.4	159.259	28.999	2493.949
	11/8/1989	1.5	9.8	9.186	15.920	23.880
AUGUST	17/8/1989	12	1.6	449.944	29.517	354.199
						23,278.508

computed individually by equations 4 and the maximum 30 min intensity, according to Wischmeier and Smith (1958). The total KE of each event was computed using the one minute time step. Monthly values were determined as the sum of the individual events determined through the EI_{30} parameter ($MJ.mm.ha^{-1}.h^{-1}$), and annual values were determined in the same manner. Then mean monthly and annual values were computed using the two years values. Only rainfall intensities greater than 25 $mm.h^{-1}$ were considered. Monthly values were determined as the sum of the individual events determined by the KE>25 parameter ($MJ.ha^{-1}$) and annual values were determined in the same manner. Later the I_{30} was found and the EI_{30} was computed using the 2-years values.

RESULTS AND DISCUSSION

The I_{30} from the (Table 1) for year 1988 was 121.952 mm/hr and that for year 1989 was 88.230 mm/hr, with the respective E to be 44,043.241 J/M^2 and 23,278.508 J/M^2. The E 30 for year 1989 was 14,093.84 J mm/M^2yr and that of year 1989 was 558.68 J mm/M^2 yr. the R factor for the station has resemblance with the mean R-factor of all investigated stations which is 1330 $MJmmha^{-1}\ h^{-1}\ yr^{-1}$ with a maximum of 5611 $MJmmha^{-1}\ h^{-1}\ yr^{-1}$ at the station Locarno Montiin Ticino (south side of the Alps) and a minimum of 124 $MJmmha^{-1}\ h^{-1}\ yr^{-1}$ at the station Corvatsch in Grisons (Eastern Central Alps). The descriptive statistic of the obtained Swiss R-factor map shows similar characteristics with a mean R-factor of $1217MJmmha^{-1}\ h^{-1}\ yr^{-1}$ that ranges from 117 to 6500 $MJmmha^{-1}\ h^{-1}\ yr^{-1}$ published by Meusaburger *et al* 2012. The average R-factor values found for Switzerland are similar to the ones published by Mikos *et al.* (2006) for an alpine region in Slovenia, which range from 1580 to 2700 $MJmmha^{-1}\ h^{-1}\ yr^{-1}$ for different years of one station (Meusaburger *et al* 2012).

Conclusion

The R factor for year 1988 was 14,093.84 J mm/M^2yr and

that of year 1989 was 558.68 J mm/M^2 yr. The availability of a rainfall erosivity map is a key issue not only for soil erosion and landslide risk assessment but also for agricultural management and soil conservation practices. Rainfall erosivity, considering rainfall amount and intensity, is an important parameter for soil erosion and risk assessment under future land use and climate change.

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