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KN Singh
PhD. Scholars of SVCAET, Faculty of SWE, SVCAET, IGKV, Raipur, Chhatishgarh, India

A Dalai
PhD. Scholars of SVCAET, Faculty of SWE, SVCAET, IGKV, Raipur, Chhatishgarh, India

RR Mohanty
Instructor (Agril. Engg.) of Agro Polytechnic Centre, Rourkela, OUAT, Bhubaneswar, Odisha, India

RK Isaac
Professor Dept. of Swlem, Shuats, Allahabad, Uttar Pradesh, India

Correspondence
KN Singh
PhD. Scholars of SVCAET, Faculty of SWE, SVCAET, IGKV, Raipur, Chhatishgarh, India

Development of single rain storm erosivity models in central plateau and hill zones for Chitrakoot district

KN Singh, A Dalai, RR Mohanty and RK Isaac

Abstract
In this paper, the erosivity studies were conducted in Chitrakoot district coming under the central plateau and hills agro-climatic zone to verify the quality and representativeness of the results generated and to provide a greater understanding of the rainfall erosivity. Chitrakoot district lies between the latitudes 24° 48’ to 25° 12’ north, longitudes 80° 58’ to 81° 34’ east and elevation range of 134-252 m from mean sea level. The geographical area of Chitrakoot district is 316400 km^2. 15-years precipitation (daily based) data from 1999 to 2013 were used for calculating equations and respective determination coefficient (R^2). The daily rainfall erosivity in Chitrakoot ranged from 39.846 to 61.841 MJ mm/ha/h. Rainfall erosivity indices, based on intensity and the amount of rainfall, were computed for all precipitations. The lowest values were found in June and the highest values were found in the August in the Chitrakoot district. These equations can be useful to map rainfall erosivity for the entire area.

Keywords: determination coefficient, Rainfall erosivity indices, intensity of rainfall and rainfall erosivity

Introduction
Soil loss prediction is important to assess the risks of soil erosion (Oliveria *et al*., 2011a) [13]. Several mathematical models (empirical, conceptual and physical-based processes) have been developed to estimate soil erosivity on different spatial and temporal scales (Ferro, 2010; Moehansyah *et al.*, 2004) [4, 11]. In tropical environments, climate or specifically the volume and intensity of rainfall are the most significant cause of high soil erosion rates (Foster *et al.*, 1982) [5]. Rainfall erosivity is one of the most important factor influencing spatial and temporal variability of soil loss. The Universal Soil Loss Equation (USLE, Wischmeier and Smith, 1978) [19] and its revised forms (RUSLE, Renard *et al*., 1997; Foster, 2004) [6], make use of rainfall erosivity (R-factor) and topographical and land-use factors for estimating the annual soil loss at different spatial scales.
The subject of rainfall erosivity has been studied worldwide, and various properties of raindrops, such as intensity, velocity, size, and kinetic energy, are among the most frequently used parameters to develop erosivity indices. The A_rI_m [rainfall amount (A_r) × maximum intensity (I_m)], EI_{30} (rainfall energy × maximum 30-min intensity), and KE > 1 (total kinetic energy of all of the rain falling at more than 25 mm h^{-1}) indices are the most important rainfall erosivity indices. These 3 indices were introduced by Lal (1976) [7], Wischmeier and Smith (Salles *et al*. 2002) [16], and Hudson (Nanko *et al*. 2004) [12], respectively. To facilitate the calculation of this index, models to estimate it from other types of precipitation data (e.g. monthly or annual totals) have been developed (Renard & Freimund, 1994; Bagarello & D’Asaro, 1994; Yu & Rosewell, 1996a, b; Ferro *et al*., 1999; Yu *et al*., 2001; Mikoš *et al*., 2006; Diodato & Bellocchi, 2007) [14, 1, 20, 3, 10]. A direct computation of rainfall erosivity factors requires long-term data for both the amount and intensity of rainfall. Rainfall kinetic energy (E) in particular has often been suggested as an indicator of rainfall erosivity, i.e. ability of rainfall to detach soil particles (van Dijk *et al*., 2002) [17].
EI_{30} is calculated with method, that includes the sum of kinetic energy of individual storm and it is multiplied with the maximum precipitation amount in any given 30 min interval of a storm. The erosive power of the rain is statistically best related to the total storm energy multiplied by the maximum 30-minute storm intensity (Wischmeier, 1959) [18]. EI represents the combined effect of direct measurements; rainfall impact and surface flow for rainfall induced soil erosion (Romkens *et al*., 2002). A least squares regression model of erosivity on daily rainfall amount was then constructed after log transformation of the data points. The objective of this study is to develop the relationship between daily rainfall event and erosivity indices for

Chitrakoot district and to develop optimized models for daily single storm erosivity indices for Chitrakoot district.

Materials and Methods

Rainfall erosivity has been calculated for Chitrakoot district located in Uttarpradesh, India. Chitrakoot district lies between the latitudes 24° 48’ to 25° 12’ north, longitudes 80° 58’ to 81° 34’ east and elevation range of 134-252 m from mean sea level. 15-years precipitation (daily based) data from 1999 to 2013 were obtained from the soil and water conservation department of agriculture, Karwi, Chitrakoot (U.P.), India. Using the precipitation values (daily based data with 750-900 mm average rainfall in Chitrakoot), equations were calculated and respective determination coefficient (R^2) were also calculated.

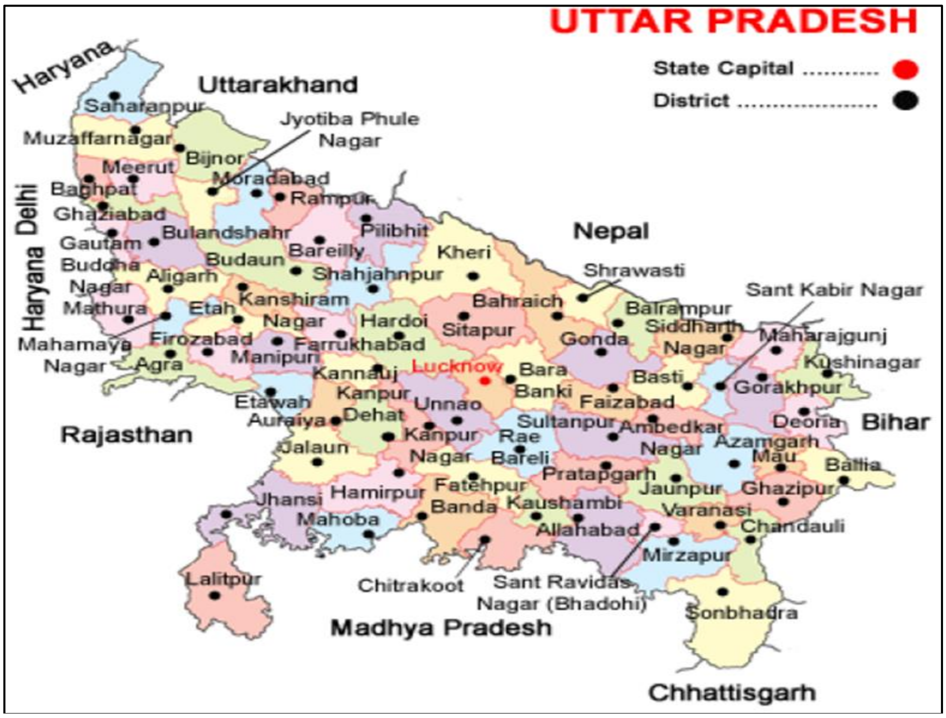

Fig 1: Map of Uttar Pradesh, India

Fig 2: Map of Chitrakoot, Uttar Pradesh, India

Estimation of short duration rainfall

The reduced maximum rainfall values were estimated using the empirical reduction formula given in eqn. by F.Y. Logah *et. al*. (2013),

$$P_t = P_{24} \left(\frac{t}{24}\right)^{\frac{1}{3}} \ldots\ldots (1)$$

Where, P_t is the required rainfall depth in mm at t-hr duration, P_{24} the daily rainfall in mm and t is the duration of rainfall.

Estimation of kinetic energy of rainstorm

Wischmeier and Smith (Salles *et al*. 2002) [16] also gave equation for calculating kinetic energy of rainstorm,

$$E = 11.87 + \{8.73 * \log (I)\} \ldots\ldots (2)$$

Kinetic energy of rainstorm is also computed by Marshal and Palmer (Salles *et al*. 2002) [16],

$$E = 8.95 + \{8.44 * \log (I)\} \ldots\ldots (3)$$

Where, E is total kinetic energy of rainfall ($J\ m^{-2}\ mm^{-1}$) and I is the rainfall intensity ($mm\ h^{-1}$).

Estimating rainfall intensity based erosivity Indices

Using rainfall and soil loss information from experimental plots, Wischmeier *et al.* (1958) concluded that the best estimator of soil loss was a compound parameter, the product of the storm kinetic energy and 30 min maximum intensity occurring during the storm.

$$EI_{30} = \text{Kinetic energy of rainstorm} \times I_{30} \ldots\ldots (4)$$

Estimating rainfall amount based erosivity Indices

A short record of measured data Mannaerts *et al* (1992) was therefore used to analyse rainfall erosivity. Erosivity expressed as kinetic energy times maximum 30-min intensity (EI_{30}), was then derived for all erosive storms (P>9 mm) using a spreadsheet technique.

$$\log EI_{30} = 1.58 \log (P_{24}) - 1.14 \ldots\ldots (5)$$

or

$$EI_{30} = 0.0723 (P_{24})^{1.58} \ldots\ldots (6)$$

Where, EI_{30} is equal to the rainfall erosivity in (MJ mm/ha/h) and P_{24} the daily rainfall amount in mm.

Result and Discussion

Erosivity index was estimated by Wischmeier's model and Manneart's model which proved to be the suitable models for Chitrakoot and comparing both the models it was seen that values estimated by these models had less variations among themselves. The estimated daily average rainfall erosivity was found to be 55.102 MJ mm/ha/h in Chitrakoot district.

Table 1: Estimated values of erosivity index by different models for Chitrakoot district

Years	Models	June (Mj Mm/Ha/H)	July (Mj Mm/Ha/H)	August (Mj Mm/Ha/H)	September (Mj Mm/Ha/H)
1999	Wischmeier	8.876	219.6079	30.64049	123.2391
	Manneart	9.943	127.0848	27.47854	81.75347
2000	Wischmeier	50.36123	50.36123	66.33383	72.00938
	Manneart	40.76362	40.76362	50.59388	53.94067
2001	Wischmeier	106.1613	124.9979	165.9449	3.666441
	Manneart	72.88194	82.64867	102.6796	4.621004
2002	Wischmeier	0	10.96155	167.9058	104.5053
	Manneart	0	11.87	103.6045	72.00315
2003	Wischmeier	17.26932	33.85697	62.19044	297.7591
	Manneart	17.28095	29.75968	48.10581	159.9956
2004	Wischmeier	7.578251	22.65669	34.95513	30.64049
	Manneart	8.695884	21.55276	30.52659	27.47854
2005	Wischmeier	76.37728	64.94181	45.40299	88.47926
	Manneart	56.47187	49.76238	37.56406	63.30485
2006	Wischmeier	8.217992	63.56066	143.0826	1.932059
	Manneart	9.315623	48.93301	91.67628	2.568244
2007	Wischmeier	5.776275	51.63006	5.216299	13.98453
	Manneart	6.888482	41.56989	6.30502	14.53019
2008	Wischmeier	28.56232	42.99526	8.876562	6.356932
	Manneart	25.97485	35.98017	9.943264	7.481824
2009	Wischmeier	0.216155	10.96155	104.5053	44.19311
	Manneart	0.204062	11.87	72.00315	36.77075
2010	Wischmeier	0	23.60589	46.62483	20.80158
	Manneart	0	22.27997	38.36004	20.11092
2011	Wischmeier	91.60582	116.296	88.47926	62.19044
	Manneart	65.03106	78.18702	63.30485	48.10581
2012	Wischmeier	14.78179	130.3289	41.80954	90.03756
	Manneart	15.20988	85.34269	35.19235	64.16708
2013	Wischmeier	292.9235	124.9979	72.00938	45.40299
	Manneart	158.0318	82.64867	53.94067	37.56406

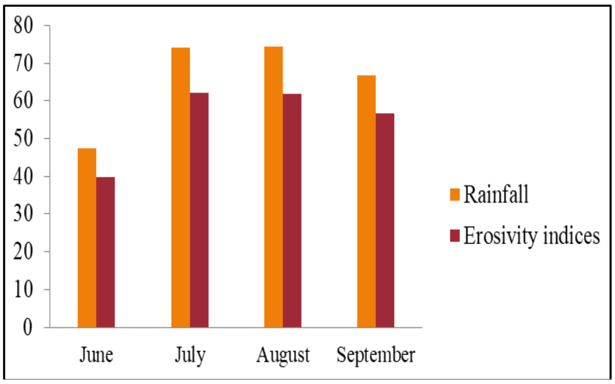

Fig 3: Variation in rainfall and erosivity indices

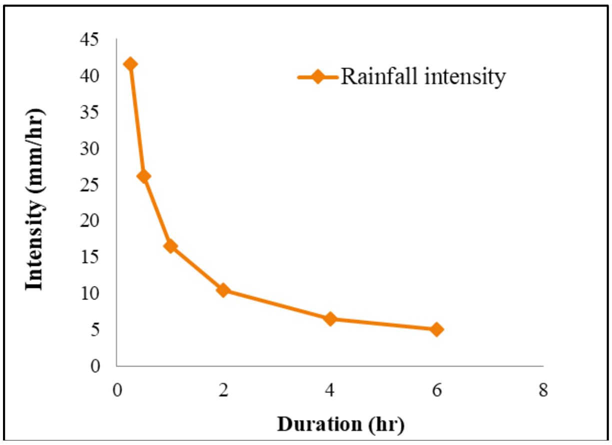

Fig 4: Intensity-Duration Curve for June

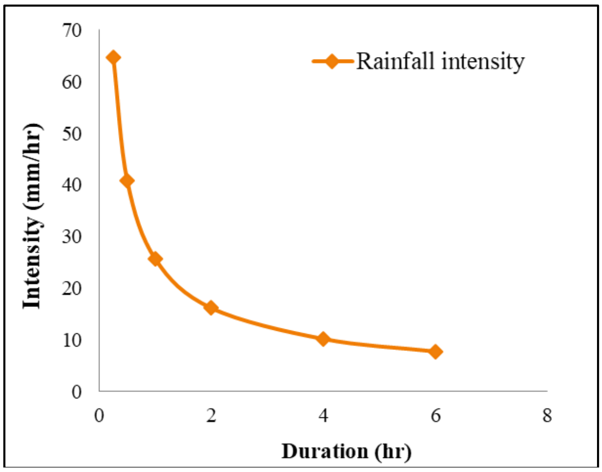

Fig 5: Intensity-Duration Curve for July

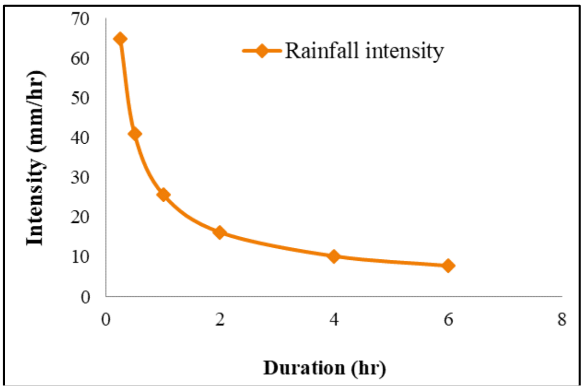

Fig 6: Intensity-Duration Curve for Aug

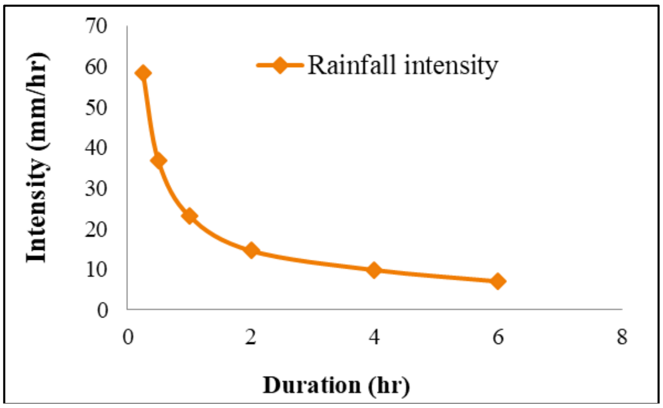

Fig 7: Intensity-Duration Curve for Sept

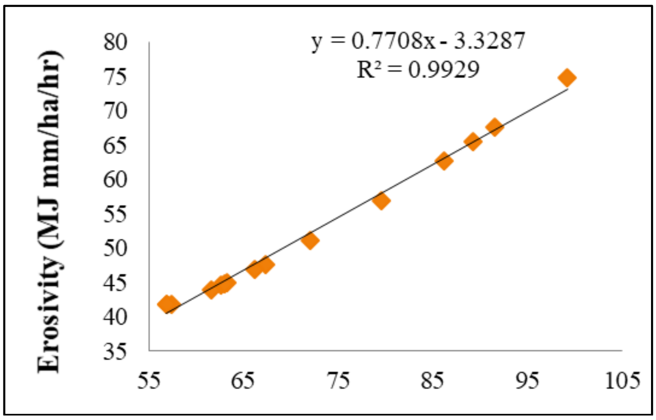

Fig 8: Rainfall event in June (mm)

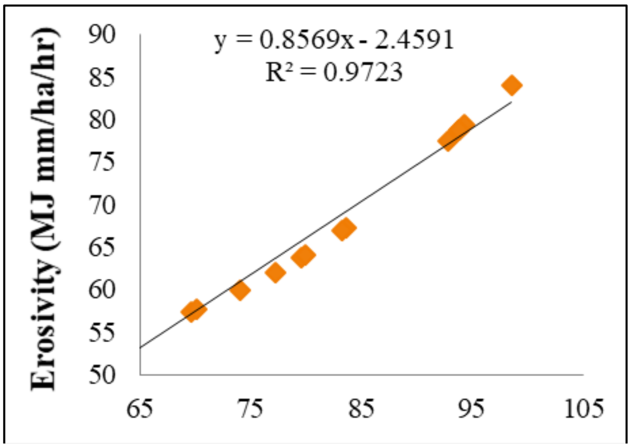

Fig 9: Rainfall event in July (mm)

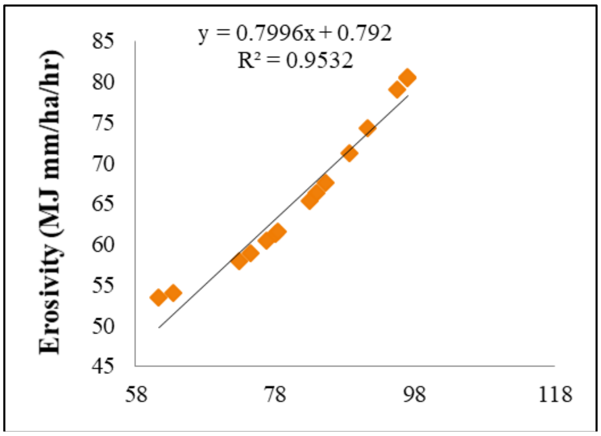

Fig 10: Rainfall event in August (mm)

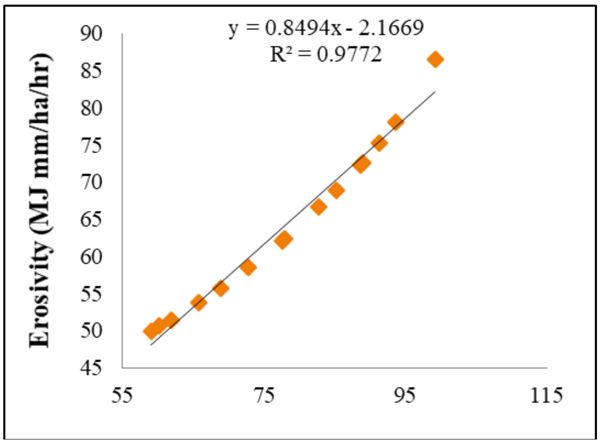

Fig 11: Rainfall event in September (mm)

Conclusion

The daily rainfall erosivity in Chitrakoot ranged from 39.846 to 61.841 MJ mm/ha/h. Rainfall erosivity indices, based on intensity and the amount of rainfall, were computed for all precipitations. The lowest values were found in June and the highest values were found in the July. It was observed that the correlation coefficients obtained for estimated erosivity indices 30-min maximum rainfall intensity EI_{30} exhibited strong linear relationship 0.9 to 1 for Chitrakoot district. The estimated value of kinetic energy by Wischmeier's model and Marshal's model has shown the variation of 1 to 3%. The erosivity index estimated by two models can be adopted for practical use.

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