



Estimation of rainfall erosivity (R) using Geo-spatial technique for the state of Tripura, India: A comparative study

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ABSTRACT

The principal-agent of soil detachment is rainfall kinetic energy (KE), which must be assessed to understand the nature of erosion, particularly in high rainfall regions, and is designated as a rainfall erosivity index (R). The present study aimed to develop and choose an appropriate model for estimating the R factor in the Indian state of Tripura. The study employed the following three models: KE>25 index model, average annual rainfall model, and monthly and average annual rainfall model. The rainfall data were collected from MOSDAC and <https://www.worldweatheronline.com> for the calculation of point R-value. The interpolation technique (Kriging) in the ArcGIS environment was adopted to find the spatial variation of the rainfall and R factor over the region. The average annual R factor of the study area was 1089.89, 533.17, and 2452.27 MJ mm/ha/h/y as calculated by Model-1, Model-2, and Model-3, respectively, for the study period (2008–17). The results show that Tripura has high rainfall erosivity which may lead to soil erosion. The comparative analysis shows Model-2 has underestimated approximately 70% whereas Model-3 has overestimated about 15% of the R factor values by considering Model-1 as base. The results demonstrate that Model-2 can be used as an alternative for estimation of rainfall erosivity in an area where the daily rainfall data is not available. These findings may help researchers to select a suitable method for the calculation of rainfall erosivity factor in mountainous catchments.

Keywords: Rainfall erosivity, Spatial variation, Temporal variation, Tripura

The rainfall-runoff erosivity factor (R) combines the effects of duration, magnitude and intensity of rainfall events, and is used to measure the potential ability of rain to cause erosion (Bonilla and Vidal 2011). There are various empirical, conceptual and physical models such as Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978), Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.* 1997) and Modified Morgan and Finney (MMF) (Morgan *et al.* 1982) which are influenced by the rainfall characteristics. The calculation of the R-factor is taken as an important parameter and computed by multiplying maximum rainfall intensity over 30 min with the kinetic energy of the rainfall (Wischmeier and Smith 1965).

However, it was found that the original method of EI_{30} calculation (Wischmeier and Smith 1965) was not very much suitable for tropical and sub-tropical zones to calculate rainfall erosivity (R) factor. Hudson (1971) gave

an alternate method for calculating the KE of rainfall and it was called KE>25 Index method. This method is based on the concept that the erosion takes place only at the threshold value of rainfall intensity. Less than that threshold value (25 mm/h), rainfall intensities do not detach the soil particles (Hudson 1971).

In both the methods, rainfall intensity is essential to calculate the kinetic energy of the rain. But in almost all developing countries of the world, recording type rain gauges are either not installed or installed with very poor density to represent any sizeable areas. Arnoldus (1980) proposed yearly, monthly, and event-based erosivity indices, which can be used to estimate the R factor for any region of the world.

The study area Tripura is a mountain state of India, receiving high amount of rainfall, which leads to severe soil erosion and landslide problems. As the R factor plays a key role in soil erosion, it becomes paramount to calculate rainfall erosivity (R) factor of Tripura. Keeping this in view, the study was conducted with the objective to find a suitable method to calculate R factor in Tripura.

MATERIALS AND METHODS

Study area: The study area, Tripura, is state of North-Eastern Region of India. It lies between latitude 23° 00' 0" N

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to 24° 30' 0" N and longitude 91° 15' 0" E to 92° 15' 0" E and the total geographical area is 10,491.69 km². The climate of the Tripura is tropical savannah. It receives average annual rainfall of 1817.71 mm and the temperature ranges from 13–27°C during winter, and during summer it ranges between 24–36°C.

Data collection: The study was conducted at North Eastern Space Application Centre (NESAC). Five Automatic Weather Stations (AWS), viz. Kumarghat, Salem, Agartala, Lambuchara and Udaipur are situated in Tripura. Hourly rainfall data were collected from the AWS (www.mosdac.govt.in) and <https://www.worldweatheronline.com>, for ten years (2008–2017). From this hourly rainfall data, we calculated daily, monthly and yearly rainfall of Tripura and it was used for determination of rainfall erosivity factor (R). In some stations, for some years, the AWS data was erratic, so the rainfall data was taken from <https://www.worldweatheronline.com>.

Computation of rainfall erosivity (R)

KE>25 Index Model: Erosivity is the sole property of rainfall, which can be quantitatively evaluated as the potential ability of rain to cause erosion in the given circumstances. For computing kinetic energy (KE) of rainfall, Wischmeir and Smith (1965) introduced EI₃₀ Index method, which is based on the product of kinetic energy of the storm and 30 min maximum rainfall intensity.

$$KE = 0.119 + 0.0873 \log_{10} I \quad I \leq 76 \text{ mm/h} \quad (1)$$

$$KE = 0.283, \quad I > 76 \text{ mm/h}$$

where KE, Kinetic Energy (MJ/ha. h); I, Rainfall intensity (mm/h)

The KE>25 Index Method is an alternate method for computing the rainfall erosivity for tropical storms (Hudson 1971). This method is based on the concept that the erosion takes place only at threshold value of rainfall intensity. From the experiment, Hudson found that the rainfall intensities <25 mm/h are not able to detach the soil particles. Thus, this method takes into account only

those rainfall intensities, which are greater than 25 mm/h.

Average annual rainfall model: Taking the average annual rainfall from the storm data Sing *et al.* (1981) developed an equation to calculate the rainfall erosivity for the different zones of India, the derived equation is given below,

$$R = 79 + 0.363 \cdot R_N \quad (2)$$

where R_N, the average annual rainfall in mm.

Using this formula, many studies have been done in different parts of India and they generated the rainfall runoff erosivity map with the help of ArcGIS (Karthick *et al.* 2017; Parveen and Kumar 2012).

Monthly and average annual rainfall model: EI₃₀ index methods can only be applied in areas, which are equipped with autographic recorders. To overcome this problem, an alternative formula was developed by Wischmeier and Smith (1978) and modified by Arnoldus (1980) which involves only annual and monthly precipitation to determine the R factor. The equation is given below.

$$R = \sum_{i=1}^{12} 1.735 \times 10^{(1.5 \log_{10} \left(\frac{p_i^2}{P} - 0.08188 \right))} \quad (3)$$

where R, rainfall erosivity factor (MJ mm/ha/h/y); p_i, monthly rainfall (mm); P, the annual rainfall (mm).

Many studies have been done in India and abroad for calculating rainfall erosivity (R) (Prasannakumar *et al.* 2012, Rahaman *et al.* 2015, Ganasri and Ramesh 2016, Thomas *et al.* 2017) with this model.

The spatial interpolation techniques (Kriging) available in the ArcGIS software were used along with rainfall erosivity for assessing the spatial variability in the study area.

RESULTS AND DISCUSSION

Hourly rainfall data as collected from MODAC was converted to monthly and annual data for all the five AWSs of Tripura. In some stations, for some years, the AWS data was not smooth so the rainfall data from <https://www.worldweatheronline.com> was taken. The intensity was

Table 1 Annual rainfall for five stations in Tripura

Year	Station				
	Agartala	Kumarghat	Lambuchara	Udaipur	Salem
2008	880.0*	1308.0	1398.0*	1770.9	1141.0
2009	995.2*	1639.0	1425.0*	2041.0	899.0*
2010	1302.0*	899.0	1354.0 *	1141.0	1024.3
2011	1380.0*	1745.0	1521.0	1468.0	1141.0*
2012	1404.0	1286*	1187.0	1469.0	942.7
2013	1391.0	1077.7	1635.0	1860.2	850.0*
2014	1412.0	1021.0	1369.5*	1788.5	1052.9
2015	735.0	1287.7	1929.0	2225.0	1050.3
2016	699.0	686.0	1222.0	2143.8	1102.6
2017	993.0	887.7	1258.0*	2272.0	1125.5*

Source: <https://www.worldweatheronline.com>

calculated from the variable graph in MOSDAC in many cases and used for calculation of EI_{30} . Station wise annual rainfall from 2008–17 is given in the Table 1.

Index Model: The average erosivity (R) index by $KE>25$ in Tripura ranged from 458.19 MJ mm/ha/h/y to 2610.30 MJ mm/ha/h/y. Udaipur had the highest R and

annual erosivity was found to be ranging from 1175.23 MJ mm/ha/h/y to 5750.42 MJ mm/ha/h/y. Lembuchera and Kumarghat showed similar erosivity indices of 1880.95 MJ mm/ha/h/y and 1886.58 MJ mm/ha/h/y, respectively. Many researchers around the world have used this model as a base model for calculation of the R factor and also developed

Table 2 R factor as calculated by different methods for Tripura

	Year	Agartala	Kumarghat	Lambuchara	Udaipur	Salem
<i>R factor by $KE>25$ model</i>						
Method 1	2008	-	1160.11	1130.26	2530.25	574.06
	2009	-	1430.01	-	1175.23	-
	2010	1257.35	1646.29	-	1288.92	-
	2011	1302.16	3432.07	1186.98	2679.93	-
	2012	781.58	2535.24	1865.18	5750.42	342.31
	2013	822.25	-	2243.86	3015.24	-
	2014	1077.22	-	1569.46	4621.21	-
	2015	1159.92	-	2960.35	1771.93	-
	2016	675.9	1115.79	2210.58	1346.5	-
	2017	412.93	-	-	1923.35	-
	Avg R	936.16	1886.58	1880.95	2610.3	458.19
<i>R factor by annual average rainfall model</i>						
Method 2	2008	439.49	553.8	296.07	721.83	493.18
	2009	409.45	673.95	522.58	819.88	460.25
	2010	188.62	405.33	421.08	493.18	450.82
	2011	216.94	712.43	268.12	611.88	479.53
	2012	588.65	182.81	509.88	612.24	421.21
	2013	583.93	470.21	672.5	754.25	409.25
	2014	591.55	449.62	212.94	728.23	461.21
	2015	345.8	546.25	779.22	886.67	459.25
	2016	332.73	328.01	522.58	857.18	479.25
	2017	439.45	401.25	4332.3	903.73	460.25
	Avg R	410.96	472.37	465.9	738.91	460.98
<i>R factor by monthly and annual rainfall model</i>						
Method 3	2008	847.85	1970.83	2581.32	2839.55	2690.32
	2009	777.07	1850.23	1756.24	3709.75	1856.84
	2010	1497.77	2429.35	1806.25	4490.81	2170.9
	2011	2789.18	2350.2	1896.75	3713.13	1847.85
	2012	747.85	4260.52	2730.25	2696.2	2035.23
	2013	505.082	2541.23	1946.78	2326.84	1976.05
	2014	536.849	2531.36	2210.25	3463.98	1747.85
	2015	1796.45	2157.28	1856.25	5811.55	1876.84
	2016	2562.59	2397.57	1925.3	3052.03	2537.28
	2017	1277.07	3527.12	1816.25	3264.66	2048.23
	Avg R	1464.11	2601.57	2163.84	3536.85	2275.99

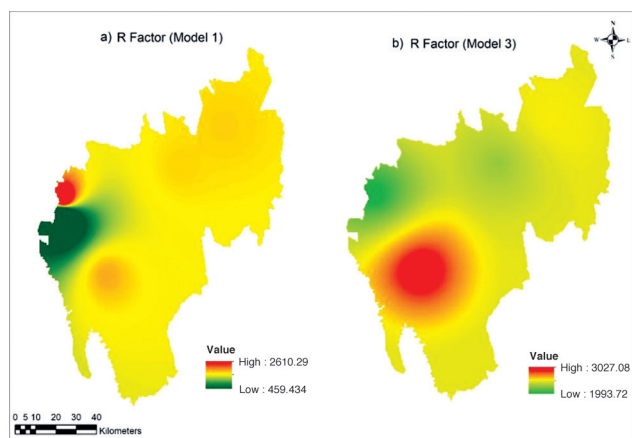


Fig 1 R factor by a) Model-1, b) Model-3

new models. Some recent studies show the similarity with these results for similar geographical regions (Zambon *et al.* 2020, Lee *et al.* 2021).

Average annual rainfall model: The average erosivity (R) index by this method in Tripura ranged from 410.9635 MJ mm/ha/h/y to 738.9114 MJ mm/ha/h/y. Udaipur had the highest R and annual erosivity was found to be ranging from 493.183 MJ mm/ha/h/y to 903.736 MJ mm/ha/h/y. Lembuchera, Kumarghat and Salem showed similar erosivity indices of 465.9061 MJ mm/ha/h/y, 472.3712 MJ mm/ha/h/y and 460.9895 MJ mm/ha/h/y, respectively. Agartala had the lowest R value of 410.9635 MJ mm/ha/h/y. Chauhan *et al.* (2020) conducted a study for Ghaggar river basin by this model and found similar results. Other researchers (Parveen and Kumar 2012, Karthick *et al.* 2017) also used this model for estimation of R factor, which showed similar ranges of values of the R factor.

Monthly and average annual rainfall model: The average erosivity (R) index by this method in Tripura ranged from 1464.11 MJ mm/ha/h/y to 3536.854 MJ mm/ha/h/y. Udaipur had the highest R and annual erosivity was found to be ranging from 2326.846 MJ mm/ha/h/y to 5811.556 MJ mm/ha/h/y. Lembuchera and Salem showed similar erosivity indices of 2163.845143 MJ mm/ha/h/y and 2275.994 MJ mm/ha/h/y, respectively. Agartala had the lowest R values of 1464.11 MJ mm/ha/h/y. Das *et al.* (2021) conducted a similar study using this model for a similar topographical region and found a high rainfall erosivity factor. The R factor for all the models is shown in Table 2 and model-1 and model-3 are shown in Fig 1.

The study area (Tripura) is situated in mountainous regions of India which faces major problem of soil loss. This problem may occur due to high rainfall as Tripura receives high average annual rainfall. This high rainfall directly influences the rainfall erosivity. Numerous studies also have revealed strong relations between rainfall erosivity and rainfall for several locations around the world (Sepaskhah and Sarkhosh 2005, Angulo-Martinez and Begueria 2009, Diodato and Bellocchi 2010, Bonilla and Vidal 2011, Lee and Heo 2011, Mukundan *et al.* 2013, Routschek *et al.* 2014, Dash *et al.* 2019, Singh and Singh 2020). The results of all

the models show that the Udaipur station received highest amount of rainfall, which resulted in highest R factor near this area. From the study, it was also observed that all the places considered in the study fall under high rainfall erosivity class, whereas Agartala has low rainfall erosivity.

In the comparative analysis amongst the three models, model-1 and model-3 gave similar results, whereas model-2 showed erratic similarity. For a similar topographical region if daily rainfall data are not available, then by using model-3 (monthly data) rainfall erosivity can be estimated. Furthermore, several studies of alike geographical domains have the evidence of using model-3 for estimation of rainfall erosivity (Das *et al.* 2021, Sujay *et al.* 2021). These findings may help researchers to select a suitable method for the calculation of rainfall erosivity factor in mountainous catchments.

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