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Erosivity Factor of the Revised Universal Soil Loss Equation (RUSLE) - A Systematized Review

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Abstract

The Revised Universal Soil Loss Equation (RUSLE) is a globally accepted erosion model which has gained good acceptability. Among the five influences of the RUSLE method of soil erosion estimation, the erosivity factor (R) represents rainfall event's ability to produce erosion. It is mainly affected by rainfall intensity and kinetic energy of the rain. The erosion index represented by EI_{30} is the most common R-factor estimation method. Due to the non-availability of rainfall intensity data in many watersheds, researchers have developed methods for erosivity estimation using rainfall depth. The Modified Fournier Index method has gained popularity. Recently, different models using machine learning techniques and ANN are also being set up to establish the R-factor for soil loss estimation. These models can estimate the R-factor quickly and more accurately. They can even predict the R-factor for the future to predict soil loss and plan conservation measures accordingly. An attempt has been made here to review different methodologies proposed by scientists across the globe for arriving at the R-factor for soil loss estimation using RUSLE model.

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EI_{30}; Erosivity; Modified Fournier Index; R-Factor; RUSLE.

Introduction

One of the most common challenges seen globally causing soil degradation is soil erosion.[1] In agricultural fields, the average rate of soil erosion varies between 0.5-400 t ha^{-1} yr^{-1}.[1,2] According to estimates, of the land getting degraded worldwide, 85% is due to erosion, which lowers production by roughly 17%, affects soil fertility and eventually causes land desertification.[3] In addition, the pattern of precipitation and temperature changes affect soil erosion rates, which ultimately influence runoff and crop production and result in floods, droughts, and hunger.[4,5]

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The erosion rate varies significantly with the intensity of rainfall, amount of rainfall, duration, and the size of rain droplets.[6] Among these, intensity plays a significant role, such that the highly intense rainfall makes the erosion processes faster.[7] Landslides, soil erosion from hillsides, and deforestation all place slopy mountain areas at risk for resource degradation. In steeper areas of Nepal, about 45.5% suffer from water erosion.[8] The changes in soil loss with the changes in rainfall depth, intensity, and the number of rainy days per year in a climate change scenario was observed, as increasing global temperature results in frequent and intense storms.[9]

Different researchers have conducted many field and laboratory studies (using rainfall simulators) to establish a link between soil erosion and the features of rainfall. The Guelph Rainfall Simulator II (GRSII) was used to simulate rainfall with various patterns and intensities and evaluation was done to find how rainfall patterns affected the soil erosion rates.[10]

RUSLE is an empirical erosion model that takes into account five aspects: erosivity (R), erodibility (K), topography r (LS), cover management (C), and conservation practice (P). The average yearly soil loss (A) can be estimated as shown in Eq. 1:

$$A = R\ K\ LS\ C\ P \qquad ...(1)$$

The erosion models consider the rainfall-related component as the most important one since it significantly impacts the erosion rate. The R-factor was incorporated into the RUSLE model to link the amount of erosion to precipitation intensity.[11,12] The potential of rain to cause erosion is called as rainfall erosivity. The erosivity depends on factors like the intensity of rainfall, raindrop particle size distribution, terminal velocity, wind velocity, slope direction, etc. Rainfall intensity has a very high impact on erosivity. Also, it is essential to have at least 20 years of pluviograph data for calculating the R-factor. This paper reviews the different approaches used by researchers to estimate the R-factor.

R-Factor Estimation

The R-factor computes the rainfall's ability to cause erosion in a field. It highlights the role of precipitation in the erosion processes. This factor clubs the rainfall characteristics like intensity, duration, and depth.[11] Among these, the intensity of rainfall most strongly influences the erosivity factor rather than duration and depth. Unfortunately, many watersheds worldwide lack recording-type rain gauges, thereby forced to derive the R-factor from rainfall depth.

Generally, The R-factor can be calculated using the techniques listed below
1. From EI_{30} Index
2. From E >25 Index
3. From rainfall depth

EI_{30} Index Method

Numerically, the R-factor is the sum of the product of the kinetic energy of rainfall (E) and the maximum 30-minute intensity, I_{30} (Eq. 2).[11,13,14]

$$R=\sum (EI_{30}) \qquad ...(2)$$

The 'E' can be calculated using Eq. 3:

$$E = 210 + 89 \log_{10} I \qquad ...(3)$$

'I' is measured in cm/h and E got in MJ/ha.cm.
The kinetic energy can also be calculated from Eq.4.

$$E= 0.119 + 0.0873 \log_{10} I \qquad ...(4)$$

E is in MJ/ ha.mm and I_{30} is in mm h-1.
Since the EI_{30} index method was initially developed for American conditions, it is not found acceptable for estimating erosivity in tropical and sub-tropical zones.

an erosivity model was established for the Dehradun district, India, to find out the values of the erosivity index and developed a good correlation between the erosivity index and Dehradun's daily rainfall values.[15] There are two different relations, linear as well as exponential, between rainfall and erosivity index. The models' performance was also assessed using statistical criteria like the absolute prediction error and coefficient of efficiency. However, after detailed analysis, it was seen that the linear model was superior.

'E >25' Index Method

This is a different approach to finding out the rainfall erosivity of tropical storms. This approach explains that erosion occurs only when rainfall intensity reaches a certain threshold. Experiments revealed that intensity of rainfall greater than 25 mm h^{-1} only cause considerable soil erosion, and hence it is only addressed by this method. The computation process is the same as that of the EI_{30} index.[16]

Both approaches use the same estimating process. However, the E >25 method is preferable since it eliminates data less than 25 mm h^{-1}. It is vital to obtain information on the amount and intensity of rainfall for both strategies. The method entails computing kinetic energy in each intensity category and then adding these values to determine the storm's overall kinetic energy. The E obtained is multiplied by the I30 to get the rainfall erosivity value. Many researchers followed Eq. 1 to derive the R-factor in the field. For example, an eight-year study was carried out in three experimental plots in the Yellow River basin, China, to develop a method for finding the R-factor of small watersheds.[17] An attempt was also made to generate the erosivity factor for the Krishnagiri watershed, Tamil Nadu.[18] The rainfall data were collected from four self-recording type rain gauge stations located within a watershed for the period from 2005 to 2009. The erosivity factor was calculated as (Eq. 5):

$$R=\sum (0.29[1- 0.72 \exp (- 0.082 I)])_i * \Delta V_i * I_{30} \quad ...(5)$$

Here unit of I is mm/h, R is MJ.mm/ha/h/y, and ΔVi the amount of rainfall for i^{th} period. The factor $\sum (0.29[1- 0.72 \exp (- 0.082 I)])_i * \Delta V_i$ in the above-mentioned equation denotes the value of kinetic energy (E).

For a small watershed in the tropical Himalayan foothills affected by slash-and-burn (*jhum*) practices, EI30 was estimated.[19] R-factor (974 MJ.mm/ha/h/y) was computed using high-resolution digital logger data collected over an extended temporal period. According to the study, annual EI_{30} was higher during rainy and summer months in comparison to post-monsoon and winter months. A substantial amount of soil was lost during this time due to the coincidence with the hum burning and clearing activities.

The rainfall erosivity factor for upper Blue Nile basin in Ethiopia at various time scales was estimated using EI_{30} method.[20] For the entire basin, the model efficiency of the monthly rainfall erosivity was 0.85. The erosivity models at the basin level are significant in planning and selecting effective soil conservation measures for watershed management.

In an experiment in Europe, rainfall data with various data (time) resolutions were collected from 28 countries, and used to calculate the R-factor using Eq. 2.[21] Finally, all these data are aggregated to 30 min resolution data to ensure homogeneity in the calculation. As a result, the erosivity factor was successfully represented in map form with a resolution of 1 km. The same formula was followed to assess the monthly R-factor in Europe.[22] Moreover, a monthly erosivity factor assessment will help identify the month and an area experiencing a high risk of soil erosion.

A study was conducted to obtain the R-factor for the Imo state of Nigeria, using 31 years of monthly rainfall data (1980-2010).[23] They estimated a mean R-factor of 199.2 MJ.mm/ha/h using Eq.3. Rainfall intensity was calculated from the amount and duration of rainfall. The rainfall erosivity map was prepared using ArcGIS software. The study obtained the highest erosivity of 6033.4 MJ/ha/h/y.

The influence of climate change in erosion-prone areas of Slovakia was also analysed.[24] To generate a relationship between the erosivity and rainfall characters, a multiple linear regression model (R2 = 0.98) was used.

R-Factor From Rainfall Depth

Several well-calibrated models are available in the literature for calculating the rainfall erosivity factor based on rainfall depth rather than intensity. Such models are ideal and highly recommended for watersheds without access to intensity data. For example, the data on the number of days in which the rainfall depth exceeded 10 mm for 27 years in Portugal was used to derive an equation for the R-factor.[25] Later, it was modified to get an R-factor for use in Malaysia using monthly and annual rainfall depth.[26] Due to the shortage of rainfall intensity data, many other researchers have used monthly and yearly rainfall depth data to compute the RUSLE R-factor.[27,28,29,30]

R-factor Estimated from Average Annual Rainfall (AAR)

To estimate the R-factor from mean annual precipitation (P), a novel erosivity model was suggested for West Africa.[31] This model can be used in areas where hourly, daily, and monthly precipitation data are unavailable. The proposed erosivity factors were R = 0.05 P,0.6 P, 0.2-0.3 P, and 0.1 P, for general cases, coastal locations, tropical, hilly, and Mediterranean regions, where P is AAR in mm. This model was also used in the Katsina region of Nigeria, which has a tropical climate with 1100 mm of annual rainfall.[32] This model was also used in the Indravati Catchment in Orissa, India.[33] The observed value was 602 MJ ha/h/y.

Another model was developed for estimating the erosivity factor of rainfall from P (in mm) (Eq. 6).[29] This model was also used in the Victoria catchment.

$$R= 47.5 + 0.38 P \quad ...(6)$$

An equation was developed for the R-factor for the entire Indian condition as follows[34]

$$R=79+0.363*AAP \quad ...(7)$$
$$\text{and } R=50+0.389*ASP \quad ...(8)$$

Where AAP=Average annual precipitation, mm; ASP=Annual seasonal rainfall, mm. The same equation was adopted to quantify erosion in the Pandavapura taluk, Karnataka.[35]

Another method was created for the R-factor, specifically for Ethiopia, from P (in mm) values (Eq.9).[36] This equation was also followed in the Koga watershed, Ethiopia.[37] The estimated R-factor in the watershed was found to be between 715.58 to 945.4 MJ ha/h/y. The same model was also applied in the Guder watershed in Ethiopia.[38]

$$R=-8.12 + 0.562 P \quad ...(9)$$

Another method was also suggested for computing the monthly R-factor using rainfall depths for the Algarve, Portugal (Eq. 10), where rain10 is the total monthly rain depth for days having rainfall greater than 10 mm, and days10 are the respective number of rainy days.[25] R-factor was computed with 23 years of precipitation data (1991–2013) for the Cameron Highlands region of Malaysia.[39]

$$R = (7.05* rain10 – 88.92* days10) \quad ...(10)$$

The model used by for the Daltonganj catchment40 was created for the Damodar Valley and is given in Eq.11.[41]

$$R = 81.5 + 0.375 P \ (340 \le P \le 3500 \text{ mm}) \quad ...(11)$$

R-factor for the Cauvery watershed was found out after considering rainfall data from 156 stations.[42] They adopted the relationship established by Singh *et al*. (1981)[34] for estimating the R-factor in India. In addition, they have interpolated the result for the study using the neighborhood method. According to research findings, the R-factor for the Erode district ranges from 320 to 480 MJ.mm/ha/h.

An erosion factor was calculated using a rainfall map created by various government entities.[5] This map depicts the P values over the district, with the R-factor calculated using Eq.12.[43]

$$R = 3 8. 5+ 0. 3 5 * P \quad ...(12)$$

The best accuracy was reported with power regression models in depicting the variability of the R-factor in Eastern Ghat highland regions of India by using data of different time intervals.[44] In addition, the R-factor for monsoon, pre- and post-monsoon periods were determined, of which mean monsoon R-factor values were found critical for soil loss predictions.

R Factor Estimation using Monthly and Annual Rainfall Depth

The R factor for a watershed (Coonoor) in Tamil Nadu, India was estimated using equation 13 given below, taking into consideration both monthly rainfall depth and annual rainfall depth.[45]

$$\boldsymbol{R = 4.17 * \frac{\sum_1^{12} Pi^2}{P} - 152} \quad ...(13)$$

R is in MJ.mm/ha/h/year, Pi- rainfall (monthly) in mm, and P- yearly rainfall in mm.

Erosivity Factor from Fournier Index

Since the intensity and daily rainfall depth data are not available in many places, for computing the erosivity factor, an index was proposed by Fourier in 1977,46 which is given by equation 14 as given below

$$F=Pm^2/P \quad ...(14)$$

Here, F represents the Fournier index, P_m represents the maximum or extreme rainfall (monthly) in mm, and P represents annual rainfall (mm).

Modified Fournier Index (MFI)

The Fournier index doesn't consider the average monthly rainfall data. It considers only the monthly maximum value. To overcome this drawback, a new index was introduced for calculating the erosivity factor called the Modified Fournier index (MFI), which is linearly connected to the R-factor.[47] MFI is the ratio of average monthly and annual rainfall. The rainfall aggressiveness is better indicated through this model (Eq. 15). Many studies have reported valid estimates of R-factor and soil loss from MFI,[48] but due to the dearth of rainfall data, the use of this model has not become much popular.

$$F = \sum_{i=1}^{12} Pi^2/P \qquad ...(15)$$

Pi and P represent monthly and annual rainfall depths respectively in millimeters.

Using the MFI, the R-factor was estimated as R = m.MFI + n, where m and n vary by area.[49] This equation was updated by Arnoldus for tropical climates, as shown in Eq. 16.

$$R = \sum_{i=1}^{12} 1.735 * 10^{(1.5\, log10\, (P_i{}^2/P) - 0.08188)} \qquad ...(16)$$

An erosivity model was created for Morocco based on the Fournier index, which was R= 0.264 $F^{1.5}$.[50] This model was used in Crete, Greece.[51] Another model was created with R= 0.6120 * $F^{1.56}$ for Sicily, Italy.[52] This model was later used in the Yialias region of Cyprus.[53]

The erosivity factor, R, is usually represented in MJ.mm/ha/h. P and P_i are measured in mm. Many researchers have applied this model in different parts of India and abroad to derive the R-factor. The model was used in Doon Valley, Uttar Pradesh, for a 52 km^2 region.[54] As this model was built specifically for tropical environments, many researchers used it in various parts of the Western Ghats, including Kerala. The model was used in the Siruvani basin, Kerala, which has an annual rainfall of 1061 mm. From 2005-2008, the erosivity factor was estimated as 23.4-36.3 MJ ha^{-1} h^{-1} y^{-1}.[55]

The same method was used in the Pamba Basin, Kerala, having a yearly rainfall of 3046 mm.[30] The estimated mean erosivity value was 1514.66 MJ/ha/h/y. This approach was also utilized for computing the R-factor in Kothagiri, Tamil Nadu.[56] The same model was used in the Sarawak region of Malaysia.[57] The area received about 350-460 cm of annual rainfall. Inter-monthly variations in precipitation led to the selection of this model, and R-factor found out as 2353 - 5380 MJ/ha/h/y.

An attempt was made to derive a temporal R-factor for the Indian condition using the Modified Fourier Index (MFI).[28] However, the R-factor was reported to be connected to the earth's superficial temperature over the years. Therefore, it is recommended to use MFI for finding out the rainfall erosivity factor when high temporal resolution rainfall data is not available. Moreover, using 30-min rainfall data, the Modified Fournier Index for 34 stations was constructed in the complicated topography of the Abruzzo area (central Italy) from 1980 to 2018.[58] They found that MFI is a reliable predictor of R (R^2 = 0.91). This model was also adopted for the low-arid climate region of south-eastern Tunisia.[59]

Precipitation Concentration index (PCI)

PCI is an indicator that strongly represents the temporal distribution of rainfall. For accounting the rainfall aggressiveness, the following index (Eq.17) was proposed.[60]

$$\boldsymbol{PCI = 100\,\frac{\sum_{1}^{12} Pi^2}{P^2}} \qquad ...(17)$$

Where Pi and P represent the monthly and annual rainfall respectively. PCI considers the monthly variation of rainfall. The PCI values range from 10 to 100 for uniform patterns to extreme patterns respectively. It takes into account the variation of monthly rainfall distribution.

Rainfall threshold for R-factor

Rainfall is one of several elements that affect soil erosion. However, all rain may not produce erosion. It is largely determined by the force exerted by raindrops. As a result, intensity plays a significant role in this. Many studies used different realistic thresholds for determining the rainfall erosivity factor from rainfall amount, understanding that rainfall amounts greater than these thresholds will only cause soil erosion.

An attempt was made to determine the practical erosive rainfall event thresholds.[17] Rainfall and runoff data for a small watershed and three plots in China's Yellow River basin were measured for the study from 1961 to 1969. The amount, average, and peak intensity of rainfall were used to compute the thresholds for amount, intensity, and peak intensity, respectively. The EI_{30} approach was used to determine the threshold, with the first step being to calculate the $EI3_0$ values for only the storms that resulted in soil loss.

Table 1: Estimation of R-factor from rainfall depth by different authors

R-factor equation	Application of the equation with description
$R = 0.002 * \sum^{n}_{i} Pi^2$ Pi is daily rainfall in mm R is in US customary unit.[61]	
Developed for West Africa. R = 0.05 P, 0.6 P, 0.2-0.3 P and 0.1 P for general cases, coastal areas, tropical hilly regions, and the Mediterranean region respectively. Unit of P -mm; R in MJ/ha/h/y)[31]	Katsina region, Nigeria. Tropical climate Rainfall 1100 mm[32] Indravati catchment, India[33]
R= 47.5 + 0.38 P[29]	Catchment of Lake Victoria[27]
R = ∑12i=1 17.35 x (1.5* log10 (Pi2/ P) - 0.08188)[47]	Doon Valley, Uttar Pradesh[54] Siruvani river basin, Kerala Rainfall-1061 mm Tropical climate[55] Pamba river basin, Kerala Rainfall- 3046mm[30] Kothagiri taluk Temperate climate[56] Manhan Mountain and Matou Mountain Range, North China Climate: Semi-arid, temperate[62]
R=-8.12 + 0.562 P Developed for Ethiopia[36]	Koga watershed, Ethiopia[37] Guder watershed, Ethiopia[38] Low arid climate,
R=(972.75 +9.95xF)/100 F-Average annual rainfall, mm[63]	Oued El Hamma Catchment, South-Eastern Tunisia[59] Kirindi Oya basin, Sri Lanka[64]
$R= 0.264 F^{1.5}$	Crete, Greece Rainfall - 900 mm
R= (972.75 +9.95xF) /100	
Developed for Morocco[50]	Semi-arid region51
R = 0.548257·P – 59.9[65]	Ghiss watershed. Morocco66
$R= 0.6120 F^{1.56}$	Yialias of Cyprus region53
Developed for Sicily Italy[52]	

The second was then utilized to calculate the cumulative EI_{30} values from the greater precipitation quantity until it reached the target EI_{30} for all erosive episodes. To determine the peak intensity thresholds, all rainfalls and associated soil losses were ordered in decreasing rainstorm amounts, and the total percentage of soil erosion was calculated. Finally, REI (Relative Error Indices) and MI (Mixing Indices) were presented to evaluate the efficacy of thresholds on rainfall erosivity estimation. The study found that determining the threshold based on peak intensity rather than average intensity and rainfall volume is a more accurate method. For erosive rainfall, three criteria were established: 1.2 cm of precipitation, 0.24 cm/h average rainfall intensity, and 13.3 mm/h for the highest 30-minute rainfall intensity.

The R-factor was derived using rainfall data (daily) for southwest Slovenia.[67] The daily rainfall depth was calculated by adding the rainfall amounts received within 24 hours (Pd). Then, several factors, including the maximum Pd (Pmax), the sum of precipitation when daily rainfall is more than 0.1 cm (P_{10}), and the days with more than 0.1 cm of rainfall (d10), were calculated. Two statistical models were employed to forecast the monthly R-factor on the basis of multiple linear regression outcomes. The efficiency coefficient 'e' was used to find the goodness of fit. RMSE was employed to compare and assess the simulated and observed values for various average periods. Utilizing the daily precipitation data, regional, and temporal analysis of rainfall erosivity was done with certain statistical models.

An attempt was made to determine the R-factor by gathering 40 years of rainfall data from 13 rain gauge stations from 1961 to 2000.[68] Erosive storm episodes were defined as rainfall of 12.5 mm or more in 15 minutes or rainfall intensity of 6 mm in 15 minutes. The R-factor was calculated using iso-erodent maps created from chosen rainfall events and statistical methods. The mean R-factor was 20 MJ/ha/h/y. The computed value was examined by comparing the ombrographic records from other stations. The two variants were considered in this study, Variant I: for all storms with rainfall >1.25 cm or intensity >0.6 cm 15 min-1, and Variant II: for all storms with rain less than 1.25 cm or strength >0.625 mm/15 min. Variant I yielded an R-factor of 57.2, while Variant II yielded an R-value of 45.6. Therefore, the R-factor derived with Variant I is thought to be the most appropriate. In a study conducted in Ethiopia's upper Blue Nile River basin, the (R) factor was calculated using 12.5 mm or more rainfall events.[20] Using Microsoft Excel, erosivity indices (annual, seasonal, monthly, and daily) were plotted against rainfall levels to build a link between rainfall and erosivity.

Researchers attempted to calculate the rainfall erosivity factor for the Slovak Republic's territories.[69] The area's one-minute rainfall data was available in digital format, making data processing considerably more effortless in the Microsoft Excel environment. Rainfall data were obtained during various periods from five gauging sites. Erosive episodes were defined as those with total rainfall of more than 12.5 mm, or intensity greater than 24 mm/h. In a semi-arid watershed, storm with less than 12.7 mm of rain, and rain periods separated by more than six hours weren't taken as erosive and the soil erosion was estimated. Therefore, they weren't used in the erosion index calculation unless the highest 15 min intensity was greater than 2.5 cm h^{-1}.

Recent Developments in Rainfall Erosivity Factor Estimation

The R-factor in the RUSLE model has undergone revisions over a period considering the selection of storm events, different equations for kinetic energy calculation, different equations to account for snowmelt and thaw, and techniques for improved spatial and temporal representations.[11,13] Spatial interpolation techniques were widely adopted for the preparation of iso erodent maps for locations with no continuous hyetograph data.[71]

Three-hour rainfall intensity satellite data from Tropical Rainfall Measuring Mission was used for estimating event-based R-factor and monthly and yearly estimates in Daling River Basin, Liaoning Province, China.[72] The data had a good correlation with interpolated data estimated from rain gauges. Satellite data is the best strategy for soil erosion modeling (spatial and temporal) in data-lacking stations.

An artificial neutral network (ANN) was adopted for spatial interpolation of erosivity indices using the EI30 and KE>25 approaches in Espirito Santo, Brazil.[73] The predicted values for homogeneous areas were almost similar, indicating the potential of the ANN technique over other interpolation techniques (Inverse distance weighed and Kriging methods).

Erosivity density (ratio of rainfall erosivity and precipitation) was used along with the R-factor for analyzing intra-annual variability of intensity and erosivity of rainfall in Greece.[74] Higher values of monthly erosivity density values indicate a high risk of frequent and intense erosive storms. The study reported November month as the most dangerous one.

A comparison was done between two models for the Westrapti River basin in Nepal: one with daily rainfall data and another with sub-hourly data.[75] The yearly average R-factor was predicted as 3514.6 MJ mm ha^{-1} h^{-1} y^{-1}, and soil loss as 8.1 t ha^{-1} y^{-1}. The future soil loss under RCP 4.5 and 8.5 was predicted and it was found that the soil loss may increase by about 10% by the end of the century (2075-2099).

An efficient methodology was developed for monthly R-factor determination using total monthly precipitation and maximum precipitation data on an hourly and daily basis in Korea.[76] The method employed machine learning algorithms and deep neural networks for the predictions and use of one-minute interval rainfall data ensured good accuracy of predictions. The trained model was tested for six sites out of 50 sites.

An attempt was done to estimate the rainfall erosivity using machine learning techniques and Bayesian optimization to carry out the estimation for areas in Italy and Switzerland.[77] The model was developed, trained and optimized with a Bayesian algorithm. The results indicate that the model could reasonably estimate the rainfall erosivity for the average rainfall events but could not estimate the erosivity values accurately for the extreme rainfall events.

A remotely sensed grid dataset of national and global precipitation was used for mapping rainfall erosivity over India.[78] R-factor was also derived using empirical equations and were compared with the MFI, which showed a high correlation between the data. It was the first attempt for the national assessment of the R-factor in India, by using remote sensing to overcome the limitations of rain gauge data availability. The R-factor for the Indian condition was estimated as 1200 MJ mm/ha/h/y.

Conclusion

One of the critical components of RUSLE erosion model is the rainfall erosivity factor (R-factor). Rainfall parameters such as intensity, volume, and duration significantly impact soil erosion. Most studies used the estimated R-factor from rainfall intensity, particularly the standard EI_{30} index. Since rainfall intensity data is not available in many watersheds, several researchers proposed different approaches for the estimation of erosivity from rainfall depth. In this notion, the Fournier and Modified Fournier indices are the most widely used approach. Because not all rain causes erosion, most studies used rainfall thresholds of 12 cm to ensure that rain less than that does not induce erosion. Research is also being carried out to estimate the R-factor using different modeling techniques, which may result in a more accurate estimation of the R-factor.

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Conflict of Interest

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References

1. Sreepriya P., Balasubramania R. Soil degradation in Kerala state and a case study on socio-economic impact due to flood in its Idukki district. *J.of Applied and Natural Science.* 2020; 12(2):159 -164. https://doi.org/10.31018/jans.vi.2265.
2. Pimentel D., Allen J., Beers A., Guinand L., Linder R., McLaughlin P., Meer B., Musonda D., Perdue D., Poisson S., Siebert S., Stoner K., Salazar R. and Hawkins A. World Agriculture and Soil Erosion. *BioScience.* 1987; 37(4):277–283. https://doi.org/10.2307/1310591.
3. Singh G., Panda R. K. Grid-cell based assessment of soil erosion potential for identification of critical erosion prone areas using USLE, GIS and remote sensing: A case study in the Kapgari watershed, India.

International Soil and Water Conservation Research 2017; 5(3): 202–211. https://doi.org/10.1016/j.iswcr.2017.05.006.

4. Thapa P., Upadhyaya P. S. Vulnerability assessment of indigenous (communities to climate change in Nepal. *J. of Land management and Geomatics Education*. 2019.
5. Thapa P. Spatial estimation of soil erosion using RUSLE modeling: a case study of Dolakha district, Nepal. *Environ Syst Res.* 2020; 9:15. https://doi.org/10.1186/s40068-020-00177-2
6. de Almeida W.S., Seitz S., de Oliveira L. F. C., de Carvalho D. F. Duration and intensity of rainfall events with the same erosivity change sediment yield and runoff rates. 2021; 9(1): 69-75. Int. Soil and Water *Conserv. Res.* https://doi.org/10.1016/j.iswcr.2020.10.004.
7. Fraser A. I., Harrod T. R., Haygarth P. M. The effect of rainfall intensity on soil erosion and particulate phosphorus transfer from arable soils. Wat.Sci.Tech. 1999; 39(12):41-45, https://doi.org/10.2166/wst.1999.0527
8. Chalise D., Kumar L., Kristiansen P. Land degradation by soil erosion in Nepal: A review. *Soil Systems.* 2019; 3(1):1–18. https://doi.org/10.3390/soilsystems3010012.
9. Nearing M. A., Pruski F. F., O'Neal M. R. Expected climate change impacts on soil erosion rates: A review. *J. Soil Water Conserv.* 2004; 59(1): 43-50.
10. Ahmed S. I., Rudra R. P., Gharabaghi B., Mackenzie K., Dickinson W.T. Within-storm rainfall distribution effect on soil erosion rate. *Int. Scholarly Res. Network Soil Sci.* 2012. https://doi.org/10.5402/2012/310927.
11. Wischmeier W. H., Smith D. D. Predicting Rainfall Erosion Losses - A Guide to Conservation Planning. Agriculture Handbook No. 537, US Department of Agriculture Science and Education Administration, Washington, 163p. 1978.
12. Koirala P., Thakuri S., Joshi S., Chauhan R. Estimation of Soil Erosion in Nepal using a RUSLE modeling and geospatial tool. *Geosciences (Switzerland).* 2019; 9(4). https://doi.org/10.3390/geosciences9040147
13. Renard K. G., Foster G. R., Weesies G. A., McCool D. K., Yoder D. C. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture Handbook No. 703, USDA-ARS. 1997.
14. Morgan R. P. C. Soil Erosion and Conservation. Blackwell Publishing, UK, 304p. 2005.
15. Ali J. Development of daily rainfall erosivity model for Dehradun, Uttarakhand, India. *International J. Current Engg and Technology.* 2015; 5(5):3222-3227.
16. Hudson N. W. Soil conservation. In: Morgan, R. C. P., Soil Erosion &Conservation. Longman Group UK Limited. 1981; 198 p
17. Xie Y., Liu B., Nearing M.A. Practical thresholds for separating erosive and non-erosive storms. *Trans. Am. Soc. Agric. Eng.* 2002; 45(6): 1843-1847. doi:10.13031/2013.11435.
18. Elangovan A. B., Ravichandran S. Estimating rainfall erosivity of the revised universal soil loss equation from daily rainfall depth in Krishanagiri watershed region of Tamil Nadu, India. In: *Environmental and Computer Science*. Proc. of an International Conference, Singapore. Asia-Pacific Chemical, Biological and Environmental Engineering Society. 2011; pp. 48-52.
19. Rawat J. S., Joshi R. C., Mesia M. Estimation of erosivity index and soil loss under different land uses in the tropical foothills of Eastern Himalaya (India). *Trop. Ecol.* 2013; 54(1): 47-58.
20. Nigussie T.A, Fanta A, Melesse A.M, Quraishi S. Modeling rainfall erosivity from daily rainfall events, Upper Blue Nile basin, Ethiopia. In: Melesse, A.M. (ed.), *Nile River Basin.* Springer International Publishing Switzerland. 2014; 307-336. DOI:10.1007/978-3-319-02720-3_17
21. Panagos P, Ballabio C, Borrelli P, Meusburger K, Klik A, Rousseva S, Tadic M.P, Michaelides S, Hrabalikova M, Olsen P, Aalto J, Lakatos M, Rymszewicz A, Dumitrescu A, Begueria S, and Alewell C. Rainfall erosivity in Europe. *Sci. Total Environ.* 2015; 511: 801-814. https://doi.org/10.1016/j.scitotenv.2015.01.008
22. Ballabio C, Borrelli P, Spinoni J, Meusburger K, Michaelides S, Begueria S, Klik A, Petan S, Janecek M, Olsen P, Aalto J, Lakatos, Rymszewicz A, Dumitrescu A, Tadic MP, Diodato N, Kostalova J, Rousseva S, Banasik

K, Alewell C and Panagos P. Mapping monthly rainfall erosivity in Europe. *Sci. Total Environ.* 2017; 579: 1298-1315. https://doi.org/10.1016/j.scitotenv.2016.11.123.

23. Okorafor O.O, Akinbile C.O, Adeyemo A and Egwuonwu C.C. Determination of rainfall erosivity index (R) for Imo state, Nigeria. Am. J. Eng. Res. 2017; 6(2): 13-16. DOI: 10.13140/RG.2.2.28897.76649
24. Valent P, Vyleta R. Estimating Rainfall Erosivity Factor Using Future Climate Projection in the Myjava Region (Slovakia). *Acta Horticulturae et Regiotecturae – Special Issue, Nitra, Slovaca Universitas AgriculturaeNitriae.* 2021. 31–36. https://doi.org/10.2478/ahr-2021-0007
25. Loureiro N.S, Coutinho M.A. A new procedure to estimate the RUSLE EI_{30} index, based on monthly rainfall data and applied to the Algarve region, Portugal. *J. hydrol.* 2001; 250: 12-18. 10.1016/s0022-1694(01)00387-0.
26. Shamshad A, Azhari M. N, Isa M.H, Hussin W.M.A.W, Parida B.P. Development of an appropriate procedure for estimation of RUSLE EI30 index and preparation of erosivity maps for Pulau Penang in Peninsular Malaysia, *Catena.* 2008; 72:423-432, https://doi.org/10.1016/j.catena.2007.08.002.
27. Lufafa A., Tenywa M. M., Isabirye M., Majaliwa M. J. G., Woomer P.L. Prediction of soil erosion in a Lake Victoria basin catchment using a GIS-based universal soil loss model. *Agric. Syst.* 2003; 76: 883-894. https://doi.org/10.1016/S0308-521X(02)00012-4
28. Maurya N. K., Tanwar P. S. Estimation of Temporal R-factor Based on Monthly Precipitation Data. J. of Physics: Conference Series. 2021; 2070:012210. doi:10.1088/1742-6596/2070/1/012210.
29. Moore T. R. Rainfall erosivity in east Africa: Kenya, Tanzania, Uganda. *Phys. Geogr.* 1979; 61: 3-4, 147-156. https://doi.org/10.1080/04353676.1979.11879987
30. Prasannakumar V., Vijith H., Abinod S., Geetha N. Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using revised universal soil loss equation (RUSLE) and geo-information technology. *Geosci. Front.* 2012; 3(2): 209-215. https://doi.org/10.1016/j.gsf.2011.11.003
31. Roose E. L. Erosion et ruissellementen Afrique de l'ouest: vingtannées de mesuresen petites parcellesexpérimentales, Adiopodoumé, Ivory Coast, Retrieved from https://horizon.documentation.ird.fr/exl-doc/pleins_textes/pleins_textes_6/Tra_d_cm/09011.pdf. 1975.
32. Adediji A., Tukur A. M., Adepoju K. A. Assessment of revised universal soil loss equation (RUSLE) in Katsina area, Katsina state of Nigeria using remote sensing (R.S.) and geographic information system (GIS). *Iran. J. Energy Environ*. 2010; 1(3): 255-264.
33. Vemu S., Pinnamaneni U. B. Estimation of spatial patterns of soil erosion using remote sensing and GIS: a case study of Indravati catchment. *Nat. Hazards.* 2011; 59: 1299-1315. https://doi.org/10.1007/s11069-011-9832-6
34. Singh G., Babu R., Chandra S. Soil Loss Prediction Research in India. Bulletin Nos.T-12/D-9. Central Soil and Water Conservation Research and Training Institute, Dehradun, 1981.
35. Vinay M., Ramu B, Mahalingam. Quantification of Soil Erosion by Water Using GIS and Remote Sensing Techniques: A Study of Pandavapura Taluk, Mandya District, Karnataka, India, *APRN Journal of Earth Sciences.* 2015; 4(2), 103-110.
36. Hurni H. Erosion-productivity-conservation systems in Ethiopia. In: [anonymous] (eds), Soil Conservation. Proceedings of paper presented at the 4th international conference, 3-9 November 1985, Maracay, Venezuela.
37. Gelagay H. S., Minale A. S. Soil loss estimation using GIS and remote sensing techniques: a case of Koga watershed, northwestern Ethiopia. *Int. Soil Water Conserv.* Res. 2016; 4: 126-136. https://doi.org/10.1016/j.iswcr.2016.01.002
38. Duguma T. A. Heliyon Soil erosion risk assessment and treatment priority classification: A case study on guder watersheds , Abay river basin , Oromia , Ethiopia. *Heliyon*. 2022; 8(April), e10183. https://doi.org/10.1016/j.heliyon.2022.e10183
39. Sholagberu A. T., Mustafa M. R. U., Yusof K. W., Ahmad M. H. Evaluation of rainfall-runoff erosivity factor for Cameron highlands,

Pahang, Malaysia. *J. Ecol. Eng*. 2016; 17(3): 1-8. DOI: 10.12911/22998993/63338.

40. Tirkey A. S., Pandey A. C., Nathawat M.S. Use of satellite data, GIS and RUSLE for estimation of average annual soil loss in Daltonganj watershed of Jharkhand (India). *J. Remote Sens. Technol*. 2019; 1(1): 20-30. 10.18005/JRST0101004
41. Babu R., Dhyani B. L, Kumar N. Assessment of erodibility status and refined iso-erodent map of India. *Indian J. Soil Conserv.* 2004; 32(2): 171-177.
42. Brema J., Hauzinger J. Estimation of the Soil Erosion in Cauvery Watershed (Tamil Nadu and Karnataka) using USLE. IOSR *Journal of Environmental Science, Toxicology and Food Technology.* 2016; 10(2): 01-11.
43. Morgan R .P. C., Morgan D. D. V., Finney H. J. A Predictive model for the assessment of soil erosion risk. J. Agric. Eng. Res. 1984; 30: 245-253.
44. Dash C. J., Das N. K., Adhikary P. Rainfall erosivity and erosivity density in Eastern Ghats Highlands of east India. *Nat. Hazards.* 2019; 97(1): 727-746. https://doi.org/10.1007/s11069-019-03670-9
45. Saravanan S., Jennefer J., Singh L., Thyagarajan S., Sankaralingam S. Impact of land-use change on soil erosion in the Coonoor Watershed, Nilgiris Mountain Range, Tamil Nadu, India. Arabian Journal of Geosciences. 2021; 14:407. https://doi.org/10.1007/s12517-021-06817-w
46. FAO.1977. Assessing soil degradation. FAO Soils Bulletin 34.
47. Arnoldus H. M. J. An approximation of the rainfall factor in the universal soil loss equation. In: Boodt, M.D. and Gabriels, D. (eds.). *Assessment of Soil Erosion.* John Wiley and Sons, Chichester*,* Gran Bretana. 1980; pp.127-132.
48. Coman A. M, Lacatusu G., Macsim A. M., Lazar G. Assessment of soil erosion using Fournier indexes to estimate rainfall erosivity. *Env. Engg. Manag. J.* 2019.18(8): 1739-1745.
49. Ferro V., Giordano G., Iovino M. Isoerosivity and erosion risk map for Sicily. *Hydrol. Sci. J*. 1991; 36(6): 549-564. https://doi.org/10.1080/02626669109492543.
50. Renard K.G., Freimund J. R. Using monthly precipitation data to estimate the R-factor in the revised USLE. *J. Hydrol.* 1994; 157: 287-306. https://doi.org/10.1016/0022-1694(94)90110-4.
51. Kouli M., Soupios P., Vallianatos F. Soil erosion prediction using the revised universal soil loss equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. *Environ. Geol.* 2008; 57: 483-497. DOI: 10.1007/s00254-008-1318-9.
52. Ferro V., Porto P., and Yu B. A comparative study of rainfall erosivity estimation for Southern Italy and Southeastern Australia. *Hydrol Sci J.* 1999; 44(1): 3-24. https://doi.org/10.1080/02626669909492199.
53. Alexakis D.D., Hadjimitsis D.G,, Agapiou A. Integrated use of remote sensing, GIS and precipitation data for the assessment of soil erosion rate in the catchment area of "Yialias" in Cyprus. *Atmos. Res.* 2013;13: 108-124. https://doi.org/10.3390/rs11091106
54. Jain K. S,, Kumar S,, Varghese J. Estimation of soil erosion for a Himalayan watershed using GIS technique. Water Resour. Manag. 2001; 15: 41-54.https://doi.org/10.1023/A:1012246029263.
55. Prasannakumar V., Shiny R., Geetha N. , Vijith H. Spatial prediction of soil erosion risk by remote sensing, GIS and RUSLE approach: a case study of Siruvani river watershed in Attapady valley, Kerala, India. *Environ. Earth Sci.* 2011; 64: 965-972. 10.1007/s12665-011-0913-3
56. Kumar M. K., Annadurai R., Ravichandran P.T. Assessment of soil erosion susceptibility in Kothagiri taluk using revised universal soil loss equation (RUSLE) and geo-spatial technology. *Int. J. Sci. Res.* Publ. 2014; 4(10): 1-13.
57. Vijith H., Seling L.W., Dodge-Wan D. Estimation of soil loss and identification of erosion risk zones in a forested region in Sarawak, Malaysia, northern Borneo. *Environ. Dev. Sustain*. 2017; 20, 1365–1384. https://doi.org/10.1007/s10668-017-9946-4.
58. Lena D. B., Curci G., Vergni L. Analysis of rainfall erosivity trends 1980–2018 in a complex terrain region (Abruzzo, central

italy) from rain gauges and gridded datasets. *Atmosphere.* 2021; 12(6). https://doi.org/10.3390/atmos12060657

59. Jemai S., Kallel A., Agoubi B., Abida H. Soil Erosion Estimation in Arid Area by USLE Model Applying GIS and RS: Case of Oued El Hamma Catchment, South-Eastern Tunisia. *Journal of the Indian Society of Remote Sensing.* 2021; 49(6), 1293–1305. https://doi.org/10.1007/s12524-021-01320-x.
60. Oliver J. E. Monthly precipitation distribution: a com-parative index. *Professional Geographer.* 1980; 32, 3, 300–309.
61. Mishra Y. Raindrop and soil erosion. Bulletin of the National Institute of Agricultural Science. 1951; 1: 1–59. (In Japanese with English summary).
62. Fu A., Cai Y., Sun T., and Li F. Estimating the impact of land cover change on soil erosion using remote sensing and GIS data by USLE model and scenario design. *Scientific Programming*, 2021; https://doi.org/10.1155/2021/6633428
63. Premalal R. Development of an erosivity map for Sri Lanka. A Research Report Submitted for the B.Sc. Degree, Department of Agricultural Engineering, University Peradeniya, Kandy, Sri Lanka. 1986.
64. Wijesundara N. C., Abeysingha N. S., Dissanayake D. M. S. L. B. GIS-based soil loss estimation using RUSLE model: a case of Kirindi Oya river basin, Sri Lanka. *Modeling Earth Systems and Environment.* 2018; 4(1):251–262.
65. Nguyen T. H. *Identify the factors effect to soil erosion and forecast soil erosion on slope land.* 1996. Water Resources University of Vietnam (Thuyloi University), Ha¬noi [Ph.D. thesis, in Vietnamese]
66. Taher M., Mourabit T., Bourjila A., Saadi O., Errahmouni A., El Marzkioui F., El Mousaoui, M. An Esimation of Soil Erosion Rate Hot Spots by Integrated USLE and GIS Methods: a Case Study of the Ghiss Dam and Basin in Northeastern Morocco. *Geomatics and Environmental Engineering*. 2022; 16(2), 95–110. https://doi.org/10.7494/geom.2022.16.2.95
67. Petkovsek G., Mikos M. Estimating the R-factor from daily rainfall data in the sub-mediterranean climate of southwest Slovenia. *Hydrol. Sci. J.* 2004; 49(5): 869-877. https://doi.org/10.1623/hysj.49.5.869.55134
68. Janecek M., Kubatova E., Tippl M. Revised determination of the rainfall-runoff erosivity factor R for application of USLE in the Czech Republic. *Soil Water Res.* 2006; 1(2): 65-71.
69. Antal J., Maderkova L., Cimo J., Drgonova K. Analysis of calculation methods for determination of rain erosivity for Slovak Republic. *Acta Sci. Pol. FormatioCircumiectus.* 2015; 14(4): 5-14. DOI: 10.15576/ASP.FC/2015.14.4.5
70. Krishna A. P. R. Estimation of soil erosion in semi-arid watershed using RUSLE model through GIS (M. Tech Thesis). Tamil Nadu Agricultural University, Coimbatore, India. 2017.
71. Yin S., Nearing M. A, Borrelli P., Xue X. Rainfall erosivity: An Overview of Methodologies and Applications, *Vadose Zone J.* 2017; 16(12): 1-16. doi:10.2136/vzj2017.06.0131.
72. Zhu Q., Chen X., Fan Q., Jin H., Li J. A new procedure to estimate the rainfall erosivity factor based on Tropical Rainfall Measuring Mission (TRMM) data. *Sci. China Technol.* Sci. 2011; 54(9): 2437-2445 https://doi.org/10.1007/s11431-011-4468-z.
73. Cecílio R.A., Moreira M..C., Pezzopane J..E..M., Pruski F..F., Fukunaga D..C. Assessing rainfall erosivity indices through synthetic precipitation series and artificial neural networks, *Annals of the Brazilian Academy of Sciences*. 2013;85(4): 1523-1535. http://dx.doi.org/10.1590/0001-3765201398012.
74. Panagos P., Ballabio C., Borrelli P., Meusburger K. Spatio-temporal analysis of rainfall erosivity and erosivity density in Greece. *Catena.* 2016. 137(1): 161-172. doi:10.1016/j.catena.2015.09.015
75. Talchabhadel R., Nakagawa H., Kawaike K., Prajapathi R. Evaluating the rainfall erosivity (R factor) from daily rainfall data: an application for assessing climate change impact on soil loss in Westrapti River basin, Nepal. *Modeling Earth Systems and Environment*. 2020; 6:1741–1762. https://doi.org/10.1007/s40808-020-00787-w.

76. Lee J., Lee S., Hong J., Lee D., Bae J.H., Yang J.E., Kim J., Lim K.J. Evaluation of rainfall erosivity factor estimation using machine and deep learning models, *Water.* 2021; 13(3): 382-400, https://doi.org/10.3390/w13030382

77. Lee S., Bae J. H., Hong J., Yang D., Panagos P., Borrelli P., Yang J. E., Kim J., Lim K. J. Estimation of rainfall erosivity factor in Italy and Switzerland using Bayesian optimization-based machine learning models. *CATENA.* 2022; 211:105957. https://doi.org/10.1016/j.catena.2021.105957.

78. Raj R., Saharia M., Chakma S., Rafieinasab A. Mapping rainfall erosivity over India using multiple precipitation dataset, *Catena.* 2022; 214(1): 106256. http://doi.org/10.1016/j.catena.2022.106256.