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Rainfall Data Analysis for Estimation of Rainfall Erosivity Factor

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Abstract

Soil erosion involves detachment and transport of soil particles from top soil layers, degrading soil quality and reducing the productivity of affected lands. The eroded soil, which ultimately accumulate on the river bed or on the bottom of reservoirs, cause inundation by decreasing the cross section area of river stream and the reduction of storage capacity of reservoirs. Soil erosion also leads to degradation of water quality. Exact estimation of the amount of soil erosion is the basic and essential step not only for the research of river morphology and water quality, but also for appropriate management of sediments and the watershed as well. Keeping this in view it is proposed to estimate the spatial distribution of soil erosion in Ram Sagar Catchment of Paralakhemundi block in Gajapati District and calculate the amount of soil erosion through a GIS based model. Revised Universal Soil Loss Equation (RUSLE) model has been considered to estimate the soil erosion. As per the Revised Universal Soil Loss Equation (RUSLE) model different climatic and physiographic parameters influence the amount of soil loss. These factors are: Rainfall Erosivity Factor, Soil Erodibility Factor, Slope Length & Steepness Factor, Cover Management Factor and Conservation Practice Factor. The rainfall erosivity factor is most important factor that significantly affects the soil erosion. This factor depends on the daily rainfall pattern and the process of arriving at this factor involves a systematic analysis of the rainfall data. The present paper highlights the data analysis and the computational process followed at arriving the Rainfall Erosivity factor. The analysis has been carried out using three year rainfall data for the study area i.e. Ram Sagar Catchment of Paralakhemundi block in Gajapati District.

Keywords:
Daily rainfall;
Rainfall Intensity;
Rainfall Erosivity Factor;
RUSLE model;

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1. Introduction

Soil erosion is a complex dynamic process which involves detachment, transport and subsequently deposition. It is a naturally occurring process and erodes top soil by the natural physical forces of water, wind or through forces associated with farming activities such as tillage.The loss of soil from agricultural land causes reduction in crop production potential, damages drainage networks and lowers the surface water quality. Soil erosion depends on various factors viz., climate, topography, soil characteristics and vegetation. The major contributing factor to soil loss and movement is rainfall and its characteristics (intensity, distribution, duration, frequency, kinetic energy). Soil erosion by rainfall causes many problems, such as decreased agricultural productivity due to the loss of arable land, increased landslide activity, ecosystem disturbance, and contaminant diffusion by the inflow of sediment to rivers, (Joon-Hak and Jun-Haeng, 2011). According to Lal, (2002); Ezemonye and Emeribe, (2012), under particular environmental conditions rainfall is the main factor driving degradation because it can erode soils and nutrients by force of raindrops. Idah*et al.*, (2008) stated that when there is too much water on the soil surface, it fills surface depressions and begins to flow, then with enough speed, surface runoff carries away the loose soil. Suresh (2012), stated equally that soil erosion occurs in three phenomena, viz; detachment, transportation and deposition. The ability of rainfall to cause soil disturbance, detachment, transport and eventual deposition which results in soil erosion is referred to as rainfall erosivity. Erosion and degradation not only decrease land productivity, but also results in major downstream or off-site damage than on-site damage.

Several models are available for estimation of erosion risk, the most commonly used model being Universal Soil Loss Equation (USLE). This model was first developed in the 1960s by Wischmeier and Smith of the United States Department of Agriculture as a field scale model (Wischmeier, 1965). It was later revised in 1997 (Renard. K. G., 1997) in an effort to better estimate the values of the various parameters that govern the USLE model and named it as Revised Universal Soil Loss Equation (RUSLE). The RUSLE incorporates improvements in better estimation of the factors based on the available data without changing the basic structure of the USLE equation. Rainfall erosivity is the main parameter to relate soil losses to erosion, which is the ability of rainfall to detach soil particles, (Sanchez-Moreno *et al*., 2013). Erosivity is the power of a storm to erode soil, it is usually determined from the characteristics of the storm, (Wang *et al.*, 2013). Rainfall erosivity is one of the factors of the USLE (Universal Soil Loss Equation by Wischmeier and Smith, 1978) and RUSLE (Revised Universal Soil Loss Equation by Renard*et al*., 1997).

2. STUDY AREA AND METHODOLOGY

2.1 Study Area Description

The objective of this study is to make use of mean monthly rainfall data to determine the rainfall erosivity index/factor of Paralakhemundi block in Gajapati District.

The study area falls within Longitude 84°6'51"E & Latitude 18°46'44"N. The climate in the study area is subtropical with high humidity. Summer is extremely hot with some thunderstorms and minor cyclones. The mean temperature ranges from min 9°C in winter, i.e. November to February to max 46°C in summer, i.e. March to mid-June. The majority of rainfall occurs during the months from mid-June to October. The daily rainfall data for the study area corresponding to the period 2014 to 2016 is extracted from the district records available at the Gajapati district collector's office.

2.2 RUSLE Model

The **RUSLE** soil erosion model is used to estimate annual soil loss value and estimate soil erosion intensity in a catchment. The RUSLE model is based on the USLE erosion model structure which was developed by Wischmeier& Smith (1978), and improved and modified by Renard et al. (1997). Five parameters are used in the RUSLE model to estimate soil loss. They are rainfall erosivity (R), soil erodibility (K), slope length and steepness factor (LS), cover management factor (C) and conservation practice factor (P). Referring to RUSLE model, the relationship is expressed as:

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

where,

A = Computed Spatial Average of total soil loss per year [$ton \cdot ha^{-1} \cdot year^{-1}$.

R = Rainfall Erosivity Factor in [$MJ\ mm \cdot ha^{-1} \cdot hr^{-1} \cdot year^{-1}$.

K = Soil Erodibility Factor [$ton \cdot ha \cdot hr \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$.

LS= Slope Length and Steepness Factor (dimensionless).

C = Land Surface Cover Management Factor (dimensionless).

P = Erosion Control or Conservation Practice Factor (dimensionless).

Rainfall erosivity is of paramount importance among natural factors affecting soil erosion, and unlike some other natural factors, such as relief or soil characteristics, is not amenable to human modification (Angelo-Martinez and Beguaria, 2009). It is due to this fact the present study is aimed at computing the factor 'R' as a first step in assessing the soil erosion at any location.

Rainfall erosivity factor is designated by R, this factor according to (Ezemonye and Emeribe, 2012; Igwe, 2012; Angelo-Martinez and Beguaria, 2009; Bhaware, 2006) depends on amount, duration, intensity, rain drop size and shape, distribution, frequency and kinetic energy. According to Wischmeier (1965), rainfall erosivity is considered to be a product of kinetic energy and 30 minute maximum rainfall intensity. Wischmeier& Smith (1978) proposed an equation for R which was later modified by Arnoldus (1980) which is as given below:

$$R = \sum_{i=1}^{n} \left(\frac{E_i I_{30}}{100} \right) \qquad --- \qquad (2)$$

In which,

R=Rainfall Factor, $MJ\ mm\ ha^{-1}\ h^{-1} y^{-1}$

E=Rainfall Kinetic Energy, $kg-m/m^2-mm$

I_{30}= Maximum intensity of rain fall during a continuous period of 30Minutes, mm/hr

n= Number of rainstorms per year

The Kinetic Energy Factor of the ith rain increment, J/m^2, is given by the equation

$$E_i = \left(210 + 87\log_{10} I_i\right) \quad --- \quad (3)$$

I_i = Average intensity of rainfall intensity in the ith increment, cm/hr

3.RESULTS

The rainfall data for the study area required in the determination of the Rainfall Factor (R) has been collected form the District Collector's Office Paralakhemundi for the year 2014 to 2016. From the overall rainfall data (Pranati Panda, 2017), the intensity of all storms exceeding a rainfall of 20 mm have been isolated since the lower magnitude rains will not in general result in any erosion. Using the filtered data of rainfall, the kinetic energy factor corresponding to all storms during the study period are evaluated and are tabulated here in tables 1 to 3.

Table 1 Kinetic Energy Factor for the Year 2014

Sl. No.	*Date*	*Rain Fall (P_i) cm*	*Duration hr*	*Intensity (I_i) cm/hr*	*Kinetic Energy (E_i)*
1	2/5/2014	2.2	0.166667	13.2	667.6779
2	10/5/2014	3.6	0.25	14.4	1104.399
3	26/5/2014	19.9	1	19.9	6348.104
4	4/6/2014	4	0.5	8	1138.275
5	11/7/2014	3.3	0.25	13.2	1001.517
6	15/7/2014	3.8	0.5	7.6	1073.997
7	16/7/2014	3.2	0.25	12.8	967.4473
8	18/7/2014	2.7	0.25	10.8	798.9512
9	19/7/2014	3.7	0.25	14.8	1138.907
10	30/7/2014	6.9	0.75	9.2	1999.962
11	13/8/2014	2	0.166667	12	599.7775
12	17/8/2014	2.5	0.25	10	732.5
13	21/8/2014	10.8	1	10.8	3195.805
14	22/8/2014	2	0.166667	12	599.7775
15	23/8/2014	2.2	0.166667	13.2	667.6779
16	26/8/2014	5.1	0.5	10.2	1498.116
17	27/8/2014	3	0.25	12	899.6663
18	28/8/2014	2.2	0.166667	13.2	667.6779
19	30/8/2014	2.8	0.25	11.2	832.3895
20	5/9/2014	2.4	0.166667	14.4	736.2661
21	6/9/2014	4.7	0.5	9.4	1366.112
22	7/9/2014	4.9	0.5	9.8	1431.96
23	24/09/2014	3.12	0.25	12.48	940.2765
24	28/09/2014	6.3	0.75	8.4	1804.397
25	1/10/2014	2.2	0.166667	13.2	667.6779
26	12/10/2014	3.1	0.25	12.4	933.4958
27	13/10/2014	16.8	1	16.8	5251.712
28	14/10/2014	10.18	1	10.18	2989.602

Table 2 Kinetic Energy Factor for the Year 2015

Sl. No.	*Date*	*Rain Fall (P_i) cm*	*Duration hr*	*Intensity (I_i) cm/hr*	*Kinetic Energy (E_i)*
1	15/04/2015	6	0.75	8	1707.413
2	18/04/2015	3	0.25	12	899.6663
3	15/6/2015	2.5	0.25	10	732.5
4	21/6/2015	5.1	0.75	6.8	1419.984
5	30/6/2015	7.4	1	7.4	2084.011
6	03/07/2015	4.4	0.5	8.8	1267.948
7	26/7/2015	3.7	0.5	7.4	1042.006
8	11/08/2015	3.3	0.5	6.6	915.0911
9	13/8/2015	3.2	0.5	6.4	883.6405
10	22/8/2015	4.6	0.5	9.2	1333.308
11	27/8/2015	3	0.25	12	899.6663
12	31/8/2015	3.4	0.5	6.8	946.6561
13	03/09/2015	7.2	1	7.2	2020.233
14	07/09/2015	3.6	0.5	7.2	1010.117
15	11/09/2015	3.3	0.5	6.6	915.0911
16	12/09/2015	2.7	0.25	10.8	798.9512
17	15/9/2015	2.1	0.25	8.4	601.4658
18	16/9/2015	4.5	0.5	9	1300.586

Storms of duration equal to 30 minutes are identified from the filtered storm data shown in tables 1 to 3 so as to arrive at the storm intensities corresponding to storms of 30 min duration. The results are presented in Table 4 here along with the maximum values of I_{30} as obtained for each year, which are required for the computation of the parameter R in equation 2.

Table 3 Kinetic Energy Factor for the Year 2016

Sl. No.	*Date*	*Rain Fall (P_i) cm*	*Duration hr*	*Intensity (I_i) cm/hr*	*Kinetic Energy (E_i)*
1	29/2/2016	3	0.25	12	899.6663
2	20/5/2016	3.9	0.5	7.8	1106.088
3	3/6/2016	2.5	0.25	10	732.5
4	8/6/2016	2.4	0.25	9.6	699.4982
5	25/6/2016	8.8	1	8.8	2535.896
6	29/6/2016	5.1	0.5	10.2	1498.116
7	30/6/2016	3.1	0.25	12.4	933.4958
8	2/7/2016	2.2	0.25	8.8	633.974
9	1/8/2016	3.6	0.5	7.2	1010.117
10	2/8/2016	2.2	0.25	8.8	633.974
11	20/8/2016	2.2	0.25	8.8	633.974
12	26/8/2016	13.86	1	13.86	4231.921
13	3/9/2016	4.24	0.5	8.48	1215.907
14	4/9/2016	2.42	0.25	9.68	706.0862
15	15/9/2016	3.5	0.5	7	978.3324
16	22/9/2016	3.8	0.5	7.6	1073.997
17	23/9/2016	6.02	0.75	8.026667	1713.861

18	24/9/2016	2.4	0.25	9.6	699.4982
19	1/10/2016	3.5	0.5	7	978.3324
20	2/10/2016	6.4	0.75	8.533333	1836.847
21	4/10/2016	2.88	0.25	11.52	859.2375
22	7/10/2016	6.1	0.75	8.133333	1739.68

The rainfall erosivity factors for the years 2014, 2015 and 2016, thus obtained using equations (1) and (2) are also indicated in this table.

Table 4 Intensities of 30 minute duration storms over the study area for 2014, 2015 and 2016.

Year	***Sl. No.***	***I_{30} (cm/hr)***	***Maximum Value of I_{30} (cm/hr)***	***Rainfall Erosivity Factor (R)***
2014	1	10.2	10.2	8661.016
	2	9.8		
	3	9.4		
	4	8		
	5	7.6		
2015	6	9.2	9.2	4798.832
	7	9		
	8	8.8		
	9	7.4		
	10	7.2		
	11	6.8		
	12	6.6		
	13	6.6		
	14	6.4		
2016	15	10.2	10.2	6592.214
	16	8.48		
	17	7.8		
	18	7.6		
	19	7.2		
	20	7		
	21	7		

Carvalho (2008) has classified the intensity of erosion in to 5 different classes as given here in following table.

Table 5 Erosivity Classification Based on Rainfall Erosivity Factor (Source: Carvalho ,2008)

EROSIVITY (MJmmha^{-1}hr^{-1})	**EROSIVITY CLASS**
R<= 2452	Low Erosivity
2452<R<=4905	Medium Erosivity
4905<R<=7357	Medium-Strong Erosivity
7357<R<=9810	Strong Erosivity
<9810	Very Strong Erosivity

From table 5, the Rainfall erosivity factors for the study area are seen to be 8661.016 MJmmha^{-1}hr^{-1}, 4798.832 MJmmha^{-1}hr^{-1} and 6592.214 MJmmha^{-1}hr^{-1} respectively for 2014,2015 and 2016. According to the classification given in table 5, the study area falls under the category of Strong Erosivity during the year 2014 and Medium-Strong Erosivity during 2016. It is noted that the erosivity is least during 2015 for the study area during the considered periods of erosion assessment.

4.Conclusion

The rainfall erosivity factor (R) is one of the key factors in the RUSLE model and has gained increasing importance as the environmental effects of climate change have become more severe. According to Wischmeier, (1965), the minimum duration for an erosive storm event is 30 minutes, based on which the rainfall erosivity of the study area for the year 2014,2015,2016 was arrived at 8661.016 $MJmmha^{-1}hr^{-1}$, 4798.832 $MJmmha^{-1}hr^{-1}$, 6592.214 $MJmmha^{-1}hr^{-1}$ respectively. Also from Table 5 the study area can be classified as an area with Strong Erosivity, Medium Erosivity, and medium- strong erosivity for three different years respectively.

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