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AL Nagargoje
M. Tech. Scholar (SWCE), Dr. ASCAET, MPKV, Rahuri, Maharashtra, India

SK Upadhye
Assistant Professor (SWCE), AICRPDA, Solapur, Maharashtra, India

SB Nandgude
Professor and Head, Department of SWCE, Dr. ASCAET, MPKV, Rahuri, Maharashtra, India

VN Barai
Associate Professor (SWCE), Dr. ASCAET, MPKV, Rahuri, Maharashtra, India

AA Atre
Professor (SWCE), Dr. ASCAET, MPKV, Rahuri, Maharashtra, India

Corresponding Author:
AL Nagargoje
M. Tech. Scholar (SWCE), Dr. ASCAET, MPKV, Rahuri, Maharashtra, India

Synthesis of rainfall characteristics for study of the erosivity pattern of Solapur district, Maharashtra

AL Nagargoje, SK Upadhye, SB Nandgude, VN Barai and AA Atre

Abstract
The rainfall erosivity is mainly influenced by the rainfall characteristics over 21 years, from 2001 to 2021. The present study examined 30 min maximum rainfall intensity, The average erosivity index calculated by EI_{30} index method which is suggested by wischmeier & Smith (1978), the threshold rainfall intensity was analyzed for thirteen sets of rainfall events *viz*., Rainfall events of all intensities (I), $I \geq 4$ mm/h, $I \geq 6$ mm/h to Rainfall events of $I \geq 26$ mm/h. The probability and recurrence interval of the annual and monthly one-day maximum rainfall and erosivity factor was calculated by using Weibull's method. Average I_{30} was found to be 15 mm/h. The average annual erosivity index for Solapur is 3563.79 MJmm/hah, which could be applicable for entire Solapur district. Threshold rainfall intensity was found 24 mm/h. The average erosivity index was found to be 2328.7 MJmm/hah using storms with intensity more than threshold value. The maximum one-day rainfall was found as 120.6 mm with 4.5% probability and 22-year return period, Maximum monthly rainfall was found as 319.8 mm with 4.5% probability and 22-year return period and the maximum annual rainfall erosivity index is observed as 6122.5 MJmm/hah with 4.5 per cent probability and 22-year return.

Keywords: Erosivity index, probability analysis, threshold rainfall intensity, kinetic energy

Introduction

Soil, water and vegetation are the most essential natural resources in an ecosystem. They are the foundation of all forms of life's sustenance. However, exploiting these valuable resources without checks and balances and with little regard for the future has resulted in their rapid depletion. The scientific management of soil and water is essential for preventing erosion, increasing agricultural production, and balancing ecosystem resources.

In many countries around the world, especially in the tropics and subtropics, soil deterioration has reached alarming proportions in recent years. In India, around 53% of the entire land surface is prone to erosion, and it is estimated that about 5,334 M tonnes of soil are detached annually for various reasons (Narayana, 1983) [10]. Soil degradation is estimated to be across 147 million hectares (Mha) of land in India, including 94 Mha due to water erosion, 14 Mha due to flooding, 9 Mha due to wind erosion and 7 Mha due to a combination of factors (Bhattacharyya *et al*., 2007) [3]. Similar levels of severe soil erosion are being experienced in Maharashtra. The annual amount of soil erosion in Maharashtra is 773.5 M tonnes, of which 94% is water-induced (Durbude, 2015) [8].

Rainfall erosivity refers to the potential for rain to produce erosion by moving small soil particles generated by the impact of raindrops on the soil. The kinetic energy of falling raindrops on the earth's surface causes soil particle separation. Runoff occurs when soil infiltration rates are lower than precipitation rates. The EI_{30} parameter expresses rainfall erosivity, one of the factors that determines erosion carried by rainstorms, along with soil erodibility, topography, vegetation, and management. This represents the product of the raindrop impact kinetic energy (E) and maximum 30 min rainfall intensity (I_{30}) (Wischmeier & Smith, 1978) [19]. The relationship of rainfall intensity and raindrop size distribution is the basis for the equations originally proposed by Wischmeier & Smith (1959) [18]. The Universal Soil Loss Equation (USLE), it is commonly quantified as the R-factor. In the USLE average annual soil loss is proportional to the rainfall erosivity when the remaining factors are constant (Wischmeier & Smith, 1978) [19]. This study will help in the assessment of soil loss and modeling/decision support systems for watershed management in the Solapur district. The return period, also known as the recurrence interval is a statistical measurement that represents the average recurrence interval over a long period, measured in years, or the expected frequency of a given event occurring at a specific location (Unger, 2006) [17].

Return period calculations are used to construct various erosion control and water conservation structures and practices (e.g., terraces, waterways, and ponds). As a result, rainfall frequency and risk should be considered while developing the adequate water control practices (Bazzano *et al*., 2007) [2]. In Solapur district, the average annual rainfall is received during the South-west monsoon period. The district contains low table land, minor isolated hills and flat or undulating topography in general. The Solapur district has a total geographical of 14844.6 square kilometers. Agriculture land covers 11480 sq.km areas which is 77.33% of the district's total area. The significant land lies under the agricultural zone. Therefore, needs to be required the study for acquiring data about soil loss; at this moment, there was no work done about the amount of soil loss in the district. This research will assist the information about soil loss through R-factor from the study area. Looking at the importance of average annual soil loss, the present study entitled, 'Synthesis of Rainfall Characteristics for Study of the Erosivity Pattern of Solapur District' is undertaken.

Materials and Methods

Materials

The research work was carried out for the Solapur district. The daily rain gauge charts of self-recording rain gauge installed at Mulegaon research farm of Zonal Agriculture Research Station, Solapur were used for determining erosivity index. The rain gauge charts for the period 2001 to 2021 were available and collected from Zonal Agriculture Research Station, Solapur Geographical location of Solapur district were presented in Table 1.

Table 1: Brief information about study area

District	Solapur
Latitude	17.10° to 18.32° N
Longitude	74.42° to 76.15°E
Elevation	458 m
Total geographical area	14,845 km^2
Average annual rainfall	573 mm
Average annual rainy days	39
Avg. max. temperature	33.8 °C
Avg. min. temperature	20.9 °C

Data Analysis

The calculation of the rainfall erosivity in this study was based on the analysis of the hyetograph, which is recorded by the self-recording type rain gauge. Each hyetograph is divided into different segments based on the change in the slope of the line. The rainfall amount and duration of each segment is measured from the graph. The kinetic energy is calculated for each segment. Multiplied by the rainfall depth during that segment, it gives the total kinetic energy of the rainfall. The sum of kinetic energies of all rainfall segments gives the total kinetic energy of rainfall, which is multiplied by the maximum thirty-minute rainfall intensity, gives the factor of rainfall erosivity. MS-Excel sub-module was used for data analysis.

Methodology

A. Erosivity index

1. Rainfall intensity (I)

The rainfall amount and duration of each storm is measured from the graph. The rainfall intensity is calculated by using following formula:

$$\text{Rainfall intensity, I (mm/h)} = \frac{Rainfall\ depth\ (mm)}{Duration\ of\ rainfall\ (h)} \quad (2.1)$$

2. 30-min Maximum Rainfall Intensity from Hyetograph (I_{30})

I_{30} is calculated from maximum amount of rainfall in 30-min for 24 h duration. This is usually calculated by visual analysis of charts. This 30-min. maximum rainfall is then converted into I_{30} (mm/hr) multiplying by two.

3. Determination of Kinetic Energy (e)

The equation given by Foster *et al.* (1981) [5] used for calculating kinetic energy of individual storm (MJ/ ha.mm). The equation given by Foster is,

$$e = (0.119 + 0.0873 \log_{10} I)\ I < 76 mm/h \quad (2.2)$$

$$e = 0.283\ I > 76 mm/h \quad (2.3)$$

Where, KE = kinetic energy, MJ/ha.mm and I = rainfall intensity, mm/h

Equations 2.2 and 2.3 were used to compute KE of all the erosive rainfall with intensity equal to or lower than 76 mm/h. Erosive rainfall with greater intensities were assumed to have a KE equal to 0.283 MJ/ha.mm, as long as the raindrop diameter does not rise up to rainfall intensities greater than this limit (Foster *et al*. 1981) [5].

4. Total Kinetic Energy (E)

The kinetic energy of individual storms is multiplied by its respective rainfall depth to get total kinetic energy (MJ/ha) of that storm.

$$E = (0.119+0.0873 \log_{10}{*}I) \times \text{Rainfall depth (mm)} \quad (2.4)$$

5. Rainfall Erosivity Factor (R)

Rainfall erosivity factor is defined as the potential ability of rain to cause erosion and is computed using following relationship:

$$R = \Sigma\ EI_{30} \quad (2.5)$$

Where

R is rainfall erosivity factor (MJ.mm/ha.h).

B. Threshold rainfall intensity

The threshold rainfall intensity for erosion in the region, i.e., the lowest value of rainfall intensity at which the soil erosion begins, was determined. The shortcoming of the EI_{30} method was that it considered all types of rainfall, which include both the erosive rain as well as nonerosive rain. To overcome this, Hudson's (1971) [7] method of KE ≥ 25 was considered suitable for tropical or subtropical regions. The concept behind this method is that low intensities are not able to do severe erosion or no erosion, or there would be a threshold value that causes erosion to that region. This method implies that the rain falling at intensities greater than 24 mm/h is considered and their kinetic energy is used to calculate the erosivity factor. The threshold rainfall intensity was analyzed for thirteen sets of rainfall events:

1. Rainfall events of all intensities (I)
2. Rainfall event with I ≥ 4 mm/h
3. Rainfall event with I ≥ 6 mm/h
4. Rainfall event with I ≥ 8 mm/h
5. Rainfall event with I ≥ 10 mm/h
6. Rainfall event with I ≥ 12 mm/h
7. Rainfall event with I ≥ 14 mm/h
8. Rainfall event with I ≥ 16 mm/h
9. Rainfall event with I ≥ 18 mm/h
10. Rainfall event with I ≥ 20 mm/h
11. Rainfall event with I ≥ 22 mm/h
12. Rainfall event with I ≥ 24 mm/h
13. Rainfall event with I ≥ 26 mm/h

The daily and annual erosivity indices were estimated for these thirteen sets. These indices were related with important rainfall characteristics such as daily precipitation and I_{30}. A set of rainfall events (threshold rainfall intensity) had been selected where coefficients of determination (R^2) for the relationships between erosivity index and daily precipitation and another relationship between erosivity index and I_{30} were high (Nandgude *et al*. 2013) [12].

C. Probability analysis of annual and monthly (one day maximum) rainfall and recurrence interval of annual erosivity factor

Rainfall data collected were analyzed for annual and monthly (One day maximum) rainfall. Data sorted out for one-day maximum rainfall and the probability of each event is calculated by Weibull's method.

$$P = \frac{M}{N+1} \qquad (2.6)$$

Where
P = probability of each event in percent.
M = order number of each event when the data are arranged in decreasing order.
N = total number of events in the data series.

Interpolation was carried out to find probability for 90, 80,…,10% chances of occurring annual and monthly one day maximum rainfall from intermediate probability. If P is probability for a rainfall greater than or equal to X, then the relationship between T (return period) and P is given by equation

$$T=1/P \qquad (2.7)$$

Where
T is return period (years),
Recurrence interval of annual erosivity factor

Weibull method was used for frequency analysis of annual erosivity index. Weibull formula for recurrence interval or return period is

$$T= n+1/m \qquad (2.8)$$

Where, T is recurrence interval (years), m is rank of the event being considered and n is number of data of annual erosivity index

Results and Discussion

Rainfall intensity

The maximum rainfall intensity was found as 133.3 mm/h in the year 2018 on 23th June followed by 131.3 mm/h in the year 2020 on 26th September and 118 mm/h in the year 2011 on 05th July respectively. Out of 21 years the maximum event of rainfall intensity was observed in the month of September (33.33%) followed by June (23.81%) and month of August (14.29%).

30-Min maximum rainfall intensity (I_{30})

I_{30} expressed in mm/h or cm/h. Higher the I_{30} more is the erosivity index (R) value. The maximum I_{30} was found as 90 mm/h in the year 2008 on 24th July and in the year 2018 on 23rd June followed by 87 mm/h in the year 2006 on 08th November and 81.4 mm/h in the year 2005 on 30th December. The maximum I_{30} varies from 27.0 mm/h (15/09/2017) to 90.0 mm/h. Average I_{30} for Solapur was found to be 15 mm/h

Kinetic Energy

The equation given by Foster *et al*. (1981) [5] was used to calculate the kinetic energy of the rainfall (Equation 2.4). The kinetic energy of rainfall depends upon rainfall intensity and rainfall depth of individual storm. The method and sample calculation of determining the kinetic energy of a storm
The storm energy was estimated by substituting the value of rainfall intensity of the storm in the Eq.2.2 for the unit depth of rainfall. To estimate the total kinetic energy of the entire storm, the storm energy of unit depth is multiplied by storm depth.

Table 2: Impact of variation in rainfall intensity and rainfall depth on the total K.E

Sr. No	Date	Rainfall Depth, Mm	Rainfall intensity, mm/h	I_{30}, mm/h	Kinetic Energy, MJ/ha.mm	Total KE, MJ/ha	Erosivity MJmm/hah
1	29-07-2001	5.0	20.0	43.0	0.233	1.163	50.00
2	18-07-2002	5.0	10.0	9.0	0.206	1.032	9.28
4	26-09-2021	5.0	5.0	18.0	0.180	0.900	16.20
5	03-09-2009	5.0	5.0	3.0	0.180	0.900	24.30
6	04-09-2016	5.0	5.0	6.0	0.180	0.900	5.40
7	25-07-2007	10.0	5.0	28.0	0.180	1.800	50.40
9	23-06-2003	2.5	5.0	5.0	0.180	0.450	8.01
12	02-10-2009	13.0	13.0	42.0	0.216	2.811	118.07
14	07-05-2015	52.0	44.4	88.0	0.263	13.668	1202.82

Table 2 shows that the some of the representative storms, which showed the impact of variation in rainfall intensity over total kinetic energy. It could be depicted from the table 4.6 that the variation in the magnitude of the total kinetic energy was due to unit increase in the magnitude of the rainfall depth than unit increase in the rainfall intensity. It was observed from the first four records of the table 4.6 that, for same rainfall depth i.e., 5 mm, when the rainfall intensity increased from 5 mm/h to 10 mm/h, 10 mm/h to 20 mm/h and 5 mm/h to 20 mm/h, the total KE increased by 14.67, 12.69 and 29.22 percent respectively.

Annual and seasonal rainfall with corresponding rainfall erosivity

From Table 3 it is observed that the annual rainfall varied between 256.40 mm in the year 2003 to 823.4 mm in the year 2020. The average annual rainfall, standard deviation and coefficient of variance is 572.9 mm, 139.8 mm and 24.4% respectively.

The maximum kharif seasonal rainfall was found as 646.1 mm in the year 2010 followed by 570.3 mm in the year 2016 and 518.2 mm in the year 2009 (Fig.4.2). For Rabi season as 324.1mm in the year 2019 followed by 213.4 mm and 175.8 mm in year of 2020 and 2009 respectively (fig.4.3). For summer season as 127 mm in the year 2014 followed by 115.4 mm and 111.2 mm in the year 2015 and 2006 respectively.

The maximum annual erosivity index was observed as 6122.48 MJmm/hah followed by 5707.68 MJmm/hah and 5433.25 MJmm/hah in the year 2018, 2019 and 2009 respectively. The standard deviation and coefficient of variation of the annually erosivity index is 1468.6 MJmm/hah and 41.2 per cent respectively. The maximum R for kharif, rabi and summer season was found to be 4750.21 MJmm/hah, 3221.26 MJmm/hah and 1993.75 MJmm/hah in the year 2018, 2019, and 2015 respectively. The maximum seasonal average erosivity index was observed in kharif (2504.42 MJmm/hah) followed by rabi (725.11 MJmm/hah) and summer (334.26 MJmm/hah). The maximum daily rainfall erosivity was found as 2235.3 MJmm/hah on 05th July, 2011

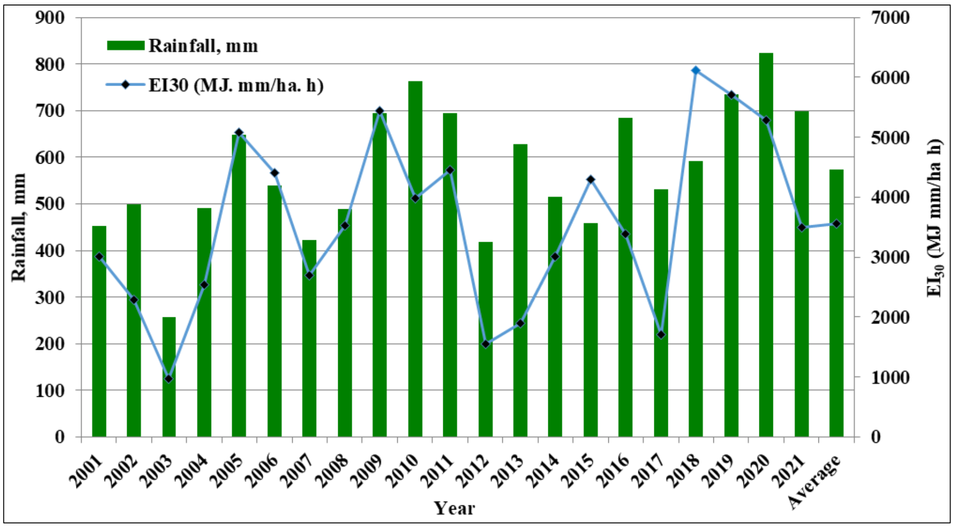

Fig 1: Year wise Annual Rainfall and Corresponding Erosivity

Table 3: Annual, summer, Kharif and Rabi Season Rainfall (mm) and corresponding Rainfall Erosivity (MJmm/hah)

Year	Annual		Summer		Kharif		Rabi	
	Rainfall, mm	EI_{30} (MJmm/hah	Rainfall, mm	EI_{30} (MJmm/hah)	Rainfall, mm	EI_{30} (MJmm/hah	Rainfall, mm	EI_{30} (MJmm/hah
2001	451.9	3015.96	0.0	0.00	334.2	1951.89	117.7	1064.07
22002	498.6	2294.78	26.2	116.62	387.3	1961.89	85.1	216.28
2003	256.4	973.23	0.0	0.00	243.7	939.91	12.7	33.32
2004	490.5	2533.32	72.4	711.06	410.4	1816.17	7.7	6.10
2005	647.1	5082.08	21.8	51.64	549.2	4605.65	76.1	424.79
2006	539.5	4400.35	111.2	652.03	320.3	1833.45	108.0	1914.87
2007	423.1	2702.98	0.0	0.00	423.1	2702.98	0.0	0.00
2008	488.2	3523.43	0.0	0.00	408.1	3204.95	80.1	318.48
2009	694.0	5433.25	0.0	0.00	518.2	3978.98	175.8	1454.27
2010	762.2	3981.86	14.5	6.70	646.1	3540.34	101.6	434.82
2011	693.5	4445.15	80.2	441.38	478.0	3223.22	135.3	780.55
2012	418.9	1553.20	31.2	71.60	275.4	993.59	112.3	488.01
2013	627.6	1894.26	58.8	222.55	495.6	1369.82	73.2	301.89
2014	515.2	3004.02	127.0	762.94	299.0	1776.64	89.2	464.44
2015	458.8	4289.11	115.4	1993.75	266.6	1727.12	76.8	568.24
2016	684.7	3380.83	47.6	213.40	570.3	2905.01	66.8	262.42
2017	531.2	1713.25	14.1	20.89	403.6	1219.84	113.5	472.52
2018	591.5	6122.48	63.4	615.06	452.2	4750.21	75.9	757.22
2019	735.8	5707.68	10.4	30.62	401.3	2455.80	324.1	3221.26
2020	823.4	5291.63	49.9	233.91	560.1	3508.99	213.4	1548.73
2021	699.4	3496.76	95.7	875.36	513.1	2126.36	90.6	495.05
Average	572.9	3563.79	44.8	334.26	426.5	2504.42	101.7	725.11
S. D	139.8	1468.6	42.1	482.4	111.1	1126.8	71.1	766.6
C.V	24.4	41.2	94.1	144.3	26.1	45.0	69.9	105.7

Average Monthly Rainfall with Corresponding Rainfall Erosivity for Solapur District

The highest average monthly rainfall was occurred in the month of September (130 mm) followed by August (107.5 mm) and July (106.5 mm) whereas the lowest average monthly rainfall 0.3 mm observed in month of February. The maximum average monthly rainfall erosivity is observed in the month of September (690.85 MJmm/hah) followed by July (670.45 MJmm/hah) and June (618.01 MJmm/hah) whereas the lowest average monthly rainfall erosivity which is observed in the month of December (0.20 MJmm/hah). This indicates that rainfall erosivity increases with rainfall. Similar result has been reported by Svetlana *et al*. (2002) [16]. From this it can be opined that rainfall in the month of September is more erosive followed by July and June Therefore, great care must be taken to protect the soil during these months. The monthly erosion index values can be used for planning soil and water conservation works and monitoring the soil erosion changes at that place over the month.

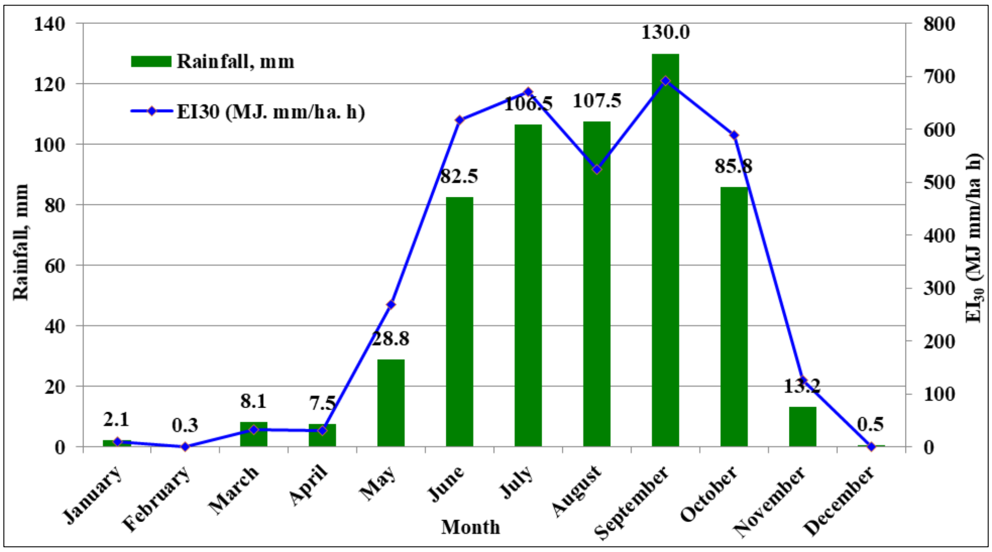

Fig 2: Average monthly rainfall and corresponding erosivity

Relation between annual rainfall and annual EI_{30}

Regression analysis was carried out by XY scatter diagram to understand the relationship between annual rainfall (X-axis) and annual EI_{30} (Y-axis). The trend line and coefficient of determination was obtained for different function. The graphical presentation of polynomial equations of second order functions, corresponding equations and R^2 values are depicted in fig 3.3. Also, the equations and R^2 values are given in the fig 3.3. The maximum value of R^2 is seen for $\mathbf{y} = -0.004x^2 + 12.54x - 1912.2$ equation.

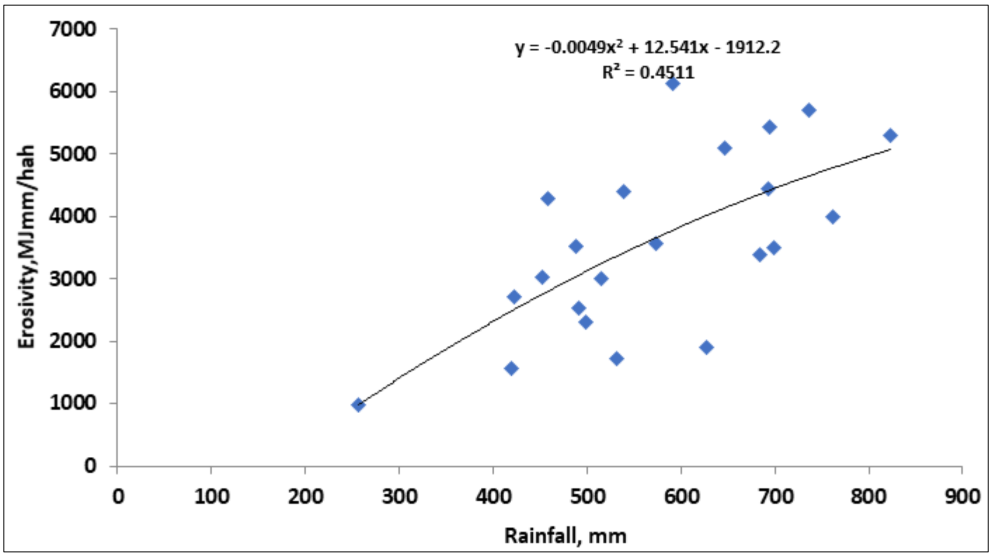

Fig 3: Relationship between Annual Rainfall and Erosivity by Polynomial Function of Order 2

Wischmeier (1959) [18] used relation with other rainfall parameters such as yearly precipitation and one hour rainfall. Rambabu *et al*. (1969) [14] estimated the relationship between EI30 and daily and monthly rainfall amounts for Dehradun region. Regression analysis was used in the current study to determine how daily precipitation and EI30 of the day correlate. The regression equations will be applied to other locations of Solapur district where rainfall intensity data is not available. (Phadtare, 2020) [13].

Threshold rainfall intensity for Solapur district

Threshold rainfall intensity is the minimum intensity to cause erosion. It gives reliable results regarding rainfall erosivity criteria. Thirteen sets with different rainfall intensities were prepared and analyzed to study relationship between erosivity indices and other important rainfall characteristics. Thirteen sets of threshold rainfall intensity are as follow

1. Erosivity for all rainfall event

The rainfall event with all intensities considered. The kinetic energy of each storm was calculated and used to estimate the erosivity index (EI_{30}). It consisted of all original reading obtained from records. The average annual erosivity with these readings was 3563.79 MJmm/hah. In these s*et al*l rainfall events were considered, which had a good effect on relationship between daily erosivity index and rainfall characteristic. The relation between daily precipitation and erosivity index depicted by XY scatter diagram by fitting different functions and corresponding R^2 value in the table 3.3. The maximum value of R^2 is observed as 0.7739 in 2^{nd} order polynomial. Trend line obtained from this method had coefficient of determination R^2 values for I_{30} and daily erosivity index (EI_{30}) as 0.8944 shown in the table 3.3. Many non-erosive rainfall events were showing influence on end results as depicted by some lower R^2 value of relationship between daily precipitation and daily erosivity index EI_{30}. So, selecting rainfall with all intensities is not advisable for study of erosion.

2. Rainfall event with I ≥ 4 mm/h

The rainfall event with intensities greater than or equal to 4 mm/h were sorted out and kinetic energy of those storms were calculated. An average annual erosivity with these readings was 3356.77 MJmm/hah. Regression analysis showed coefficient of determination (R^2) for daily I_{30} and EI_{30} and for daily precipitation (P) and daily erosivity index EI_{30} are 0.7832 and 0.8199 respectively.

3. Rainfall event with I ≥ 6 mm/h

The rainfall event with intensities greater than or equal to 6 mm/h were sorted out and kinetic energy of those storms were calculated. An average annual erosivity with these readings was 3205.53 MJmm/hah. Regression analysis showed coefficient of determination (R^2) for daily I_{30} and EI_{30} and for daily precipitation (P) and daily erosivity index EI_{30} are 0.7739 and 0.8257 respectively.

4. Rainfall event with I ≥ 8 mm/h

The rainfall event with intensities greater than or equal to 8 mm/h were sorted out and kinetic energy of those storms were calculated. An average annual erosivity with these readings was 3090.98 MJmm/hah. Regression analysis showed coefficient of determination (R^2) for daily I_{30} and EI_{30} and for daily precipitation (P) and daily erosivity index EI_{30} are 0.7696 and 0.8284 respectively.

5. Rainfall event with I ≥ 10 mm/h

The rainfall event with intensities greater than or equal to 10 mm/h were sorted out and kinetic energy of those storms were calculated. An average annual erosivity with these readings was 2976.52 MJmm/hah. Regression analysis showed coefficient of determination (R^2) for daily I_{30} and EI_{30} and for daily precipitation (P) and daily erosivity index EI_{30} are 0.7756 and 0.8501 respectively.

6. Rainfall event with I ≥ 12 mm/h

The rainfall event with intensities greater than or equal to 12 mm/h were sorted out and kinetic energy of those storms were calculated. An average annual erosivity with these readings was 2848.79 MJmm/hah. Regression analysis showed coefficient of determination (R^2) for daily I_{30} and EI_{30} and for daily precipitation (P) and daily erosivity index EI_{30} are 0.769 and 0.8639 respectively.

7. Rainfall event with I ≥ 14 mm/h

The rainfall event with intensities greater than or equal to 14 mm/h were sorted out and kinetic energy of those storms were calculated. An average annual erosivity with these readings was 2768.81 MJmm/hah. Regression analysis showed coefficient of determination (R^2) for daily I_{30} and EI_{30} and for daily precipitation (P) and daily erosivity index EI_{30} are 0.7621 and 0.8628 respectively.

8. Rainfall event with I ≥ 16 mm/h

The rainfall event with intensities greater than or equal to 16 mm/h were sorted out and kinetic energy of those storms were calculated. An average annual erosivity with these readings was 2703.83 MJmm/hah. Regression analysis showed coefficient of determination (R^2) for daily I_{30} and EI_{30} and for daily precipitation (P) and daily erosivity index EI_{30} are 0.754 and 0.8617 respectively.

9. Rainfall event with I ≥ 18 mm/h

The rainfall event with intensities greater than or equal to 18 mm/h were sorted out and kinetic energy of those storms were calculated. An average annual erosivity with these readings was 2613.78 MJmm/hah. Regression analysis showed coefficient of determination (R^2) for daily I_{30} and EI_{30} and for daily precipitation (P) and daily erosivity index EI_{30} are 0.8798 and 0.8534 respectively.

10. Rainfall event with I ≥ 20 mm/h

The rainfall event with intensities greater than or equal to 20 mm/h were sorted out and kinetic energy of those storms were calculated. An average annual erosivity with these readings was 2550.04 MJmm/hah. Regression analysis showed coefficient of determination (R^2) for daily I_{30} and EI_{30} and for daily precipitation (P) and daily erosivity index EI_{30} are 0.8823 and 0.8648 respectively.

11. Rainfall event with I ≥ 22 mm/h

The rainfall event with intensities greater than or equal to 22 mm/h were sorted out and kinetic energy of those storms were calculated. An average annual erosivity with these readings was 2448.91 MJmm/hah. Regression analysis showed coefficient of determination (R^2) for daily I_{30} and EI_{30} and for daily precipitation (P) and daily erosivity index EI_{30} are 0.8867 and 0.8703 respectively.

12. Rainfall event with I ≥ 24 mm/h

The rainfall event with intensities greater than or equal to 24 mm/h were sorted out and kinetic energies of those storms were calculated. Average annual erosivity index (EI_{30}) was 2328.7 MJmm/hah. Trend line obtained from this method had better coefficient of determination R^2 for thirty-minute maximum rainfall intensity (I_{30}) and daily erosivity index (EI_{30}) and daily precipitation (P) and daily erosivity index as 0.8856 and 0.8731 respectively.

13. Rainfall event with I ≥ 26 mm/h

The rainfall event with intensities greater than or equal to 26 mm/h were sorted out and kinetic energy of those storms were calculated. An average annual erosivity with these readings was 2328.77 MJmm/hah. Regression analysis showed coefficient of determination (R^2) for daily I_{30} and EI_{30} and for daily precipitation (P) and daily erosivity index EI_{30} are 0.8745 and 0.8730 respectively.

Table 4: Different conditions for determination of threshold rainfall intensity

Condition	Function	Coeff. of Determination. (R^2) Daily Precipitation with EI_{30}	Function	Coeff. of Determination. (R^2) Daily I_{30} with EI_{30}	No of Rainfall Event	Average Annual Rainfall, mm	Average Annual Erosivity, MJmm/hah
Erosivity for All Rainfall Events	Polynomial with order 2	R^2 = 0.7739	Polynomial with order 2	R^2 = 0.8944	751	572.93	3563.79
Erosivity for Rainfall Events with Intensities I ≥4 mm/h	Power	R^2 = 0.8199	Polynomial with order 2	R^2 = 0.7832	698	467.58	3356.77
Erosivity for Rainfall Events with Intensities I ≥6 mm/h	Power	R^2 = 0.8257	Polynomial with order 2	R^2 = 0.7739	655	421.63	3205.53
Erosivity for Rainfall Events with Intensities I ≥8 mm/h	Polynomial with order 2	R^2 = 0.8284	Polynomial with order 2	R^2 = 0.7696	612	388.38	3090.98
Erosivity for Rainfall Events with Intensities I ≥10 mm/h	Power	R^2 = 0.8501	Polynomial with order 2	R^2 = 0.7756	571	359.22	2976.52
Erosivity for Rainfall Events with Intensities I ≥12 mm/h	Polynomial with order 2	R^2 = 0.8639	Power	R^2 = 0.769	534	331.67	2848.79
Erosivity for Rainfall Events with Intensities I ≥14 mm/h	Polynomial with order 2	R^2 = 0.8628	Polynomial with order 2	R^2 = 0.7621	485	311.67	2768.81
Erosivity for Rainfall Events with Intensities I ≥16 mm/h	Polynomial with order 2	R^2 = 0.8617	Polynomial with order 2	R^2 = 0.754	451	296.47	2703.83
Erosivity for Rainfall Events with Intensities I ≥18 mm/h	Polynomial with order 2	R^2 = 0.8534	Power	R^2 = 0.8798	417	276.85	2613.78
Erosivity for Rainfall Events with Intensities I ≥20 mm/h	Polynomial with order 2	R^2 = 0.8648	Power	R^2 = 0.8823	392	264.70	2550.04
Erosivity for Rainfall Events with Intensities I ≥22 mm/h	Polynomial with order 2	R^2 = 0.8703	Polynomial with order 2	R^2 = 0.8867	363	242.70	2448.91
Erosivity for Rainfall Events with Intensities I ≥24 mm/h	Polynomial with order 2	R^2 = 0.8731	Polynomial with order 2	R^2 = 0.8856	336	224.50	2328.77
Erosivity for Rainfall Events with Intensities I ≥26 mm/h	Polynomial with order 2	R^2 = 0.8730	Polynomial with order 2	R^2 = 0.8745	296	224.50	2328.77

From Table 4, it is observed that the relation between daily precipitation and daily erosivity index improved by eliminating non-erosive rainfall event. The relation for rainfall event with intensities greater than or equal to 24 mm/h had better coefficient of determination R^2 for daily precipitation (P) and daily erosivity index (EI_{30}) and thirty-minute maximum rainfall intensity (I_{30}) and daily erosivity index (EI_{30}). Similarly, this type of regression analysis was carried out (Nandgude *et al*., 2013) [12] for the Wakavali region in western Maharashtra. They observed that the threshold intensity represents the lower limit of the erosive limit of erosive intensity had a magnitude of 8 mm/h. therefore, they considered an 8 mm/h threshold rainfall intensity for the Wakavali region. (Barai *et al*., 2014) [1] Experimented in Rahuri, district Ahmednagar, Maharashtra. Which field performance was done with the help of simulated rainfall with various combination of land slopes and rainfall intensities? The modified Morgan's cup was used with clay soil condition. They concluded that the intensity less than 26 mm/h are not able to detach the soil particle. Therefore 24 mm/h was considered as threshold rainfall intensity for Solapur district. This set was considered as reference for erosivity indices of study area.

Probability analysis and return period of annual and monthly (One day maximum) rainfall and recurrence interval of annual erosivity factor

One day maximum rainfall in year varies from 47.0 mm to 120.6 mm. The maximum one-day rainfall was found as 120.6 mm in the year 2016 on 21st July with 4.5% probability and 22-year return period. The maximum monthly rainfall was found as 319.8 mm in the month of October in the year 2019 with 4.5 percent probability and 22-year return period

For *kharif* season, maximum rainfall erosivity index is observed in the year 2018 (4750.221 MJmm/hah) with 4.5 per cent probability and 22-year return period whereas the minimum *kharif* rainfall erosivity is observed in the year 2003 (939.91 MJmm/hah) with 95.5 per cent probability and 1 year return period.

For rabi season, maximum rainfall erosivity index is observed in the year 2019 (3221.26 MJ mm/hah) with 4.5 per cent probability and 22-year return period whereas the minimum rabi rainfall erosivity is observed in the year 2004 (6.910 MJmm/hah) with 90.9 per cent probability and 1 year return period.

The maximum annual rainfall erosivity index is observed in the year 2018 (6122.5 MJmm/hah) with 4.5 per cent probability and 22-year return period. Whereas the minimum annual rainfall erosivity is observed in the year 2003 (973.2 MJmm/hah) with 95.5 per cent probability and 1 year return period.

Conclusion

1. Average I_{30} for Solapur was found to be 15 mm/h,
2. The average annual erosivity index for Solapur is 3563.79 MJmm/hah, which could be applicable for entire

Solapur district.

3. The lowest rainfall intensity causing soil erosion, which can be denoted as threshold rainfall intensity for Solapur district is 24 mm/h. The average erosivity index was found to be 2328.7 MJmm/hah using storms with intensity more than threshold value.
4. The maximum one-day rainfall was found as 120.6 mm with 4.5% probability and 22-year return period, Maximum monthly rainfall was found as 319.8 mm with 4.5% probability and 22-year return period and the maximum annual rainfall erosivity index is observed as 6122.5 MJmm/hah with 4.5 per cent probability and 22-year return period whereas minimum annual erosivity index as 973.2 MJmm/hah with 95.5 per cent probability and 1-year return period.

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