



Spatial and Temporal Analysis of Rainfall Erosivity and Its Implications for Soil Conservation in Koraput District, Odisha, India

**Ch. J. Dash^{1,*}, P. P. Adhikary², J. Lenka¹, P. Yadav¹, M. Madhu¹,
P. Kumar¹, H.C. Hombegowda¹**

¹*ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Sunabeda, Koraput, Odisha 763002, India*

²*ICAR-Indian Institute of Water Management, Bhubaneswar, Odisha 751023, India*

Abstract : Rainfall erosivity significantly influences soil erosion, offering insights into rainfall aggressiveness and its impact on soil health. This study examines the spatial and temporal variations of monthly rainfall erosivity in Koraput district, Odisha, India. The results indicate that the highest rainfall erosivity occurs in August with 2349.1 MJ mm ha⁻¹ h⁻¹ month⁻¹ (28.1% of annual rainfall erosivity), followed by July with 2122.5 MJ mm ha⁻¹ h⁻¹ month⁻¹ (25.4 %), September with 1470.9 MJ mm ha⁻¹ h⁻¹ month⁻¹ (17.6%), and June with 1267.0 MJ mm ha⁻¹ h⁻¹ month⁻¹ (15.1%). The rainfall received during the month of October contributes only 6.9% to the annual rainfall erosivity. Geospatial analysis reveals higher erosivity in Boipariguda, Dasamantapur, and Koraput blocks, while lower values are observed in the northeast, including Bandhugoan, parts of Laxmipur, and Narayanpatna. Given that June, July, August, and September exhibit critical erosivity values, implementing targeted soil and water conservation measures during these months is essential to mitigate soil degradation. These findings emphasise the need for strategic planning in soil conservation efforts to preserve soil health in erosivity-prone regions.

Key words: *Rainfall erosivity, spatial and temporal variation, soil erosion, soil health, Koraput, conservation measures*

1. Introduction

Soil erosion is a global problem with significant environmental impacts, particularly in developing regions such as Africa, South America, and Asia, notably in China and India. A recent study reports that Africa exhibits the highest average soil erosion rate at 3.88 Mg ha⁻¹ yr⁻¹, followed by South America and Asia. In India, soil erosion affects approximately 71.0% of the country's geographic area, equivalent to 85.7 million hectares, underscoring the urgent need for effective quantification and conservation measures (Jinger *et al.* 2023). The Universal Soil Loss Equation (USLE) is a widely used model for predicting soil loss, employing

the rainfall erosivity factor (R-factor), which is influenced by rainfall intensity, raindrop size, and velocity. Variability in the R-factor can significantly impact agriculture, ecosystem services, forestry, hydrology, and water management (Ballabio *et al.*, 2017).

Understanding rainfall erosivity and its spatial and temporal trends is crucial for assessing soil erosion risk and implementing appropriate soil conservation strategies (Lee *et al.*, 2011; Dash *et al.*, 2019; Singh and Singh, 2020). The Koraput district in Odisha, India, part of the Eastern Ghats, features rugged hills, plateaus, and rivers at altitudes ranging from 127 to 1655 meters above mean sea level. Agriculture is the primary livelihood for

the region's inhabitants. However, recent climatic changes have altered rainfall patterns, adversely affecting agricultural productivity. This region faces severe land degradation due to deforestation, mining activities, shifting cultivation, soil erosion, and intense rainfall, leading to a substantial decline in crop yields. In Koraput district alone, 13,333 thousand tonnes of soil are lost annually at a rate of $43.9 \text{ t ha}^{-1} \text{ yr}^{-1}$ from cultivable land (Naik *et al.*, 2015). Field experiments in the Eastern Ghats Highland Region (EGHLR) of Odisha also reported soil losses of $12.5 \text{ t ha}^{-1} \text{ yr}^{-1}$ from upland paddy fields (Adhikary *et al.*, 2017).

Given the region's susceptibility to soil erosion, understanding the rainfall erosivity factor (R-factor) is crucial for effective soil conservation planning. Therefore, this study aims to assess the spatial and temporal patterns of monthly rainfall erosivity in the Koraput district of Odisha. This assessment will provide vital information for developing targeted soil and water conservation measures to mitigate soil erosion and improve agricultural sustainability in the region. The need for strategic planning in soil conservation is further emphasised by the drastic soil losses and the variability in rainfall patterns due to climate change. By focusing on the spatio-temporal distribution of rainfall erosivity, this study aims to contribute to the broader efforts of soil conservation and sustainable land management in the Eastern Ghats and similar erosion-prone regions.

2. Material and methods

2.1. Study area

The study area spans 8379 km^2 , situated between $81^\circ 05'$ to $83^\circ 05'$ East longitude and $18^\circ 04'$ to $19^\circ 05'$ North latitude in Odisha, India (Fig. 1). The elevation ranges from 123 to 1655 m above mean sea level. The district's topography features undulating hilly regions in the east, southeast, and central parts, while plains are concentrated in the western and northwestern areas. Koraput district comprises 14 blocks: Bandhugaon, Boipariguda, Boriguma, Dasamantpur, Jeypore, Koraput, Kotapad, Kundra, Lamataput, Laxmipur, Nandapur, Narayanpatna, Pottangi, and Semiliguda. The district experiences a tropical climate with mean annual maximum and minimum temperatures of 35.8°C and 7.6°C , respectively (Adhikary *et al.*, 2015). It receives an average annual rainfall of 1452 mm over approximately 70 days, with the monsoon season contributing nearly 80% of the annual rainfall.

Koraput is predominantly a tribal district, with more than 50% of its population belonging to scheduled tribes (Census 2011). The net sown area in the district is $3,01,500 \text{ ha}$, accounting for nearly 36% of the district's total area. Agriculture is the primary livelihood, with paddy being the predominant crop. Other significant crops include finger millet (*Eleusine coracana*), foxtail millet (*Setaria italica*), niger (*Guizotia abyssinica*), little millet (*Panicum sumatrense*), black gram (*Vigna mungo*), groundnut (*Arachis hypogaea*), and pigeon pea (*Cajanus cajan*).

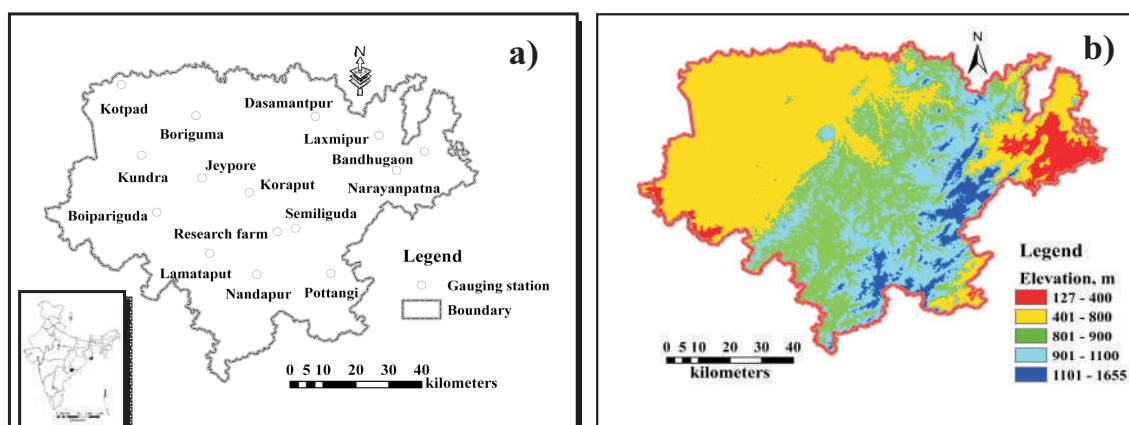


Fig. 1. Map of study area showing a) Rain gauge stations b) Elevation variation

2.2. Data acquisition and calculation of rainfall erosivity

Rainfall data were collected from 15 rain gauge stations in the Koraput district (Fig.1a). Of these, the meteorological observatory at the ICAR-Indian Institute of Soil and Water Conservation (IISWC), Research Center, Sunabeda, Koraput, Odisha is equipped with a self-recording rain gauge and others are ordinary rain gauges. For the other stations, daily rainfall data from 2000 to 2020, were sourced from the Odisha government website (<http://www.odisha.gov.in/disaster/src/rainfall/rainfall1/rainfall.html>).

The self-recording rain gauge data from the meteorological observatory at the ICAR- IISWC were used to compute kinetic energy and the R-factor over 27 years (1994-2020) using the equation provided by Brown and Foster (1987), which is presented in Equation 1.

$$KE = 0.29[1 - 0.72 \exp(-0.05i)] \dots\dots\dots (1)$$

where KE is the kinetic energy of a single rainfall event ($\text{MJ mm}^{-1} \text{ ha}^{-1}$), and i is the rainfall intensity (mm h^{-1}). Further, the maximum rainfall intensity during a 30-minute period of the rainfall event (I_{30} , mm h^{-1}) was determined, and the R-factor was estimated by multiplying kinetic energy with I_{30} . The daily rainfall erosivity factor ($\text{MJ mm ha}^{-1} \text{ h}^{-1} \text{ day}^{-1}$) was calculated by taking the sum of all by single event R-factor values. Similarly, monthly R-factor ($\text{MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$) and annual erosivity factor ($\text{MJ mm ha}^{-1} \text{ h}^{-1} \text{ yr}^{-1}$) were determined by taking the sum of daily and monthly erosivity respectively.

For the other 14 stations, rainfall erosivity was computed using the model developed by Dash *et al.* (2019).

2.3. Spatial interpolation of R factor

The Inverse Distance Weighing (IDW) is a deterministic interpolation technique which creates surfaces from sample points using mathematical functions based on extent of similarity. This simplicity of the method has made it popular (Adhikary and Dash, 2017). In IDW, the interpolated estimates are based on values at nearby locations, and it gives weight to data points such that their influence on prediction is reduced as the distance from the point increases. The interpolated value $z(x_0)$ is expressed in Eq. 1.

$$z(x_0) = \frac{\sum_{i=1}^n \frac{x_i}{h_{ij}^\beta}}{\sum_{i=1}^n \frac{1}{h_{ij}^\beta}} \dots\dots\dots (2)$$

Where x_i is the i^{th} data value, h_{ij} is the separation distance between the sample data value and the interpolated value, n is the total number of sample data values, and β is the weighting power. The estimation quality will be significantly governed by the choice of the weighting power (Mueller *et al.*, 2001; Adhikary and Dash, 2017). The optimal weighting power depends on the spatial structure of the data and is primarily influenced by the coefficient of variation, skewness, and kurtosis of the data (Mueller *et al.* 2001). The optimal power function was assessed by a series of tests of the powers ranging from 1.0 to 4.0 (Kravchenko, 1999). Like Adhikary and Dash (2017), the weighing power was selected by a series of small increments to determine the value that minimises the root mean square error of the prediction of rainfall erosivity.

3. Results and discussion

The following section deals with the block-wise distribution of rainfall events, the monthly distribution of rainfall and rainfall erosivity, and the mapping of the monthly erosivity factor in the study area.

3.1. Block wise rainfall and erosive rainfall event

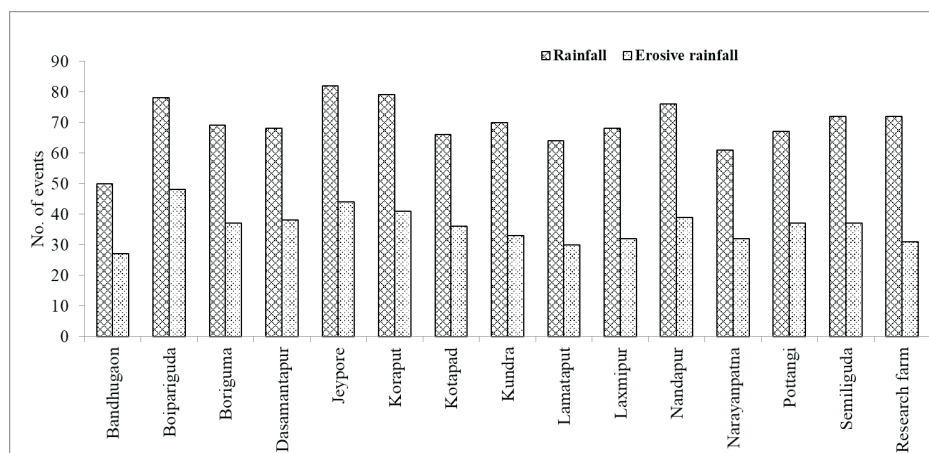


Fig. 2: Block wise distribution of rainfall and erosive rainfall event

The occurrence of the average number of rainfall events in the Koraput district is 70. For the period from 2000 to 2020, Jeypore block had the highest number of rainfall events (82), followed by Koraput (79), Boipariguda (78) and Nandapur (76), whereas Bandhugaon block had the least number of rainfall events (50). Similarly, the maximum number of erosive events (rainfall greater than 12.6 mm) was observed in Boipariguda (48), followed by Jeypore (44) and Koraput (41). The least number of erosive events occurred in Bandhugaon (30). The monthly distribution of rainfall, rainfall erosivity and their contribution towards annual rainfall and erosivity, respectively, are presented in Table 1. The

early months of the year (January through May) show low to moderate rainfall, with mean monthly values ranging from 3.1 mm in February to 48.5 mm in May. The rainfall mostly concentrates during the monsoon season, occurring between June and September, contributing nearly 84% towards annual rainfall. The maximum amount of rainfall occurs during August (370.2 mm, 26.4%), followed by July (338.1 mm, 24.1%), September (244.5 mm, 17.5%), and June (214.4 mm, 15.3%). Post-monsoon months (October to December) see a sharp decline in rainfall, with mean values dropping to 107.0 mm in October and reaching a low of 6.0 mm in December.

Table 1: Monthly variation in rainfall, rainfall erosivity, and percentage contributions in Koraput district, Odisha

Month	Rainfall (mm)			Rainfall erosivity ($\text{MJ mm ha}^{-1} \text{h}^{-1} \text{month}^{-1}$)			% contribution	
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Rainfall	Rainfall erosivity
January	0.0	13.2	5.5	1.7	54.3	21.4	0.4	0.3
February	0.0	7.7	3.1	0.0	29.6	11.2	0.2	0.1
March	2.9	26.6	11.6	10.0	119.6	47.8	0.8	0.6
April	8.9	50.6	33.2	34.8	247.6	155.3	2.4	1.9
May	25.3	69.2	48.5	113.1	352.8	237.5	3.5	2.8
Jun	149.8	271.6	214.4	843.3	1651.2	1267.0	15.3	15.1
July	212.0	496.0	338.1	1248.1	3258.3	2122.5	24.1	25.4
August	238.9	493.1	370.2	1428.6	3237.3	2349.1	26.4	28.1
September	152.3	338.1	244.5	859.2	2113.8	1470.9	17.5	17.6
October	54.3	149.6	107.0	268.3	841.9	578.9	7.6	6.9
November	6.1	44.1	18.4	22.6	212.2	80.3	1.3	1.0
December	0.9	12.8	6.0	2.7	52.5	22.7	0.4	0.3
Total			1400.6			8364.7		

The similar type of trend also observed in case of rainfall erosivity. The annual average rainfall erosivity has been estimated as $8364.7 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ yr}^{-1}$. In the early months of the year (January through May) the rainfall erosivity values are also low, with mean monthly values starting at $11.2 \text{ MJ mm ha}^{-1} \text{ h}^{-1}$ in February and increasing to $237.5 \text{ MJ mm ha}^{-1} \text{ h}^{-1}$ by May. The aggressiveness of rainfall for soil erosion mostly concentrates during monsoon season occurring between June and September, contributing nearly 86% towards annual rainfall erosivity. Rainfall erosivity has maximum value during August ($2349.1 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$, 28.14 %) followed by July ($2122.5 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$, 25.4 %), September ($1470.9 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$, 17.6%), and June ($1267.0 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$, 15.1%). The contribution of October month towards annual rainfall erosivity is less than 10%. Other months of the year have very negligible contribution towards annual rainfall erosivity. The lowest values are found in February ($0.1 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$) followed by January ($0.3 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$) and December ($0.3 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$). As the aggressive of rainfall is more during monsoon season, keeping land barren during those months may aggravate the soil erosion rate, thereby loss of soil fertility and crop production.

The data illustrates that the monsoon season (June to September) is the critical period for both rainfall and rainfall erosivity, contributing approximately 83.3% of the total annual rainfall and 86.2% of the total annual erosivity. This period's significant contribution underscores the importance of implementing robust soil and water conservation measures during these months to mitigate soil erosion effectively. The lower erosivity in the non-monsoon months suggests a reduced risk of soil erosion, although conservation efforts should still be maintained to prevent cumulative degradation over time.

3.2 Spatial distribution of monthly rainfall erosivity

The spatial variation of monthly mean rainfall erosivity factor during different months for Koraput district, Odisha has been depicted in Fig. 3, Fig. 4 and Fig. 5. During the month of February, mean rainfall

erosivity varies between 0.7 to $30.0 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$ (Fig. 3). Bandhuguan, Boriguma, Kotpad and Lamtaput have experienced lower rainfall erosivity, whereas Dasamantapur, Koraput, Nandapur and Semiliguda, observed higher rainfall erosivity. The month of March also shows a similar type of variation in rainfall erosivity (10 to $120 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$), having higher values of rainfall erosivity in Pottangi, Semiliguda, Koraput, Boipariguda and Jeypore. It can be inferred that, the months of February and March exhibit generally low rainfall erosivity values across the district. This indicates minimal potential for rainfall-induced soil erosion, and the erosivity is relatively uniform, with no significant hotspots. During April to May, there is a noticeable increase in erosivity, especially in May, during which, the entire district experienced rainfall erosivity value more than $100 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$. This suggests the beginning of more intense rainfall events that can contribute to soil erosion, as in certain areas in the central and southern parts of the district begin to show higher erosivity values.

The months of June to September show a dramatic rise in rainfall erosivity, due to occurrence of high and intense rainfall. August and July are particularly notable for their extensive high-erosivity values spreading over the entire district. The higher value of monthly rainfall erosivity during July ($2400 - 3258 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$), August ($2500 - 3237 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$) and September ($1600 - 2114 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$) has been noticed in areas covering Boipariguda, Dasamantapur, Jeypore and Koraput block, whereas lower values in north-east part of the district covering Bandhuguan, part of Laxmipur and Narayanpatna. The higher erosivity values during October ($268-842 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$), November ($23-212 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$), and December ($3-52 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ month}^{-1}$) has been shifted to eastern part of the study area. The cause may be attributed to occurrence of rainfall in those areas due to cyclonic storm in the Bay of Bengal, as these areas near to Bay of Bengal (Dash *et al.* 2019).

The spatial variation of monthly rainfall erosivity in Koraput district clearly highlights the temporal and spatial dynamics of soil erosion potential. The high erosivity during the monsoon season

necessitates targeted and timely soil conservation interventions to protect the region's soil health and agricultural productivity. By understanding these

patterns, stakeholders can better plan and implement effective soil conservation strategies, ensuring sustainable land management in the region.

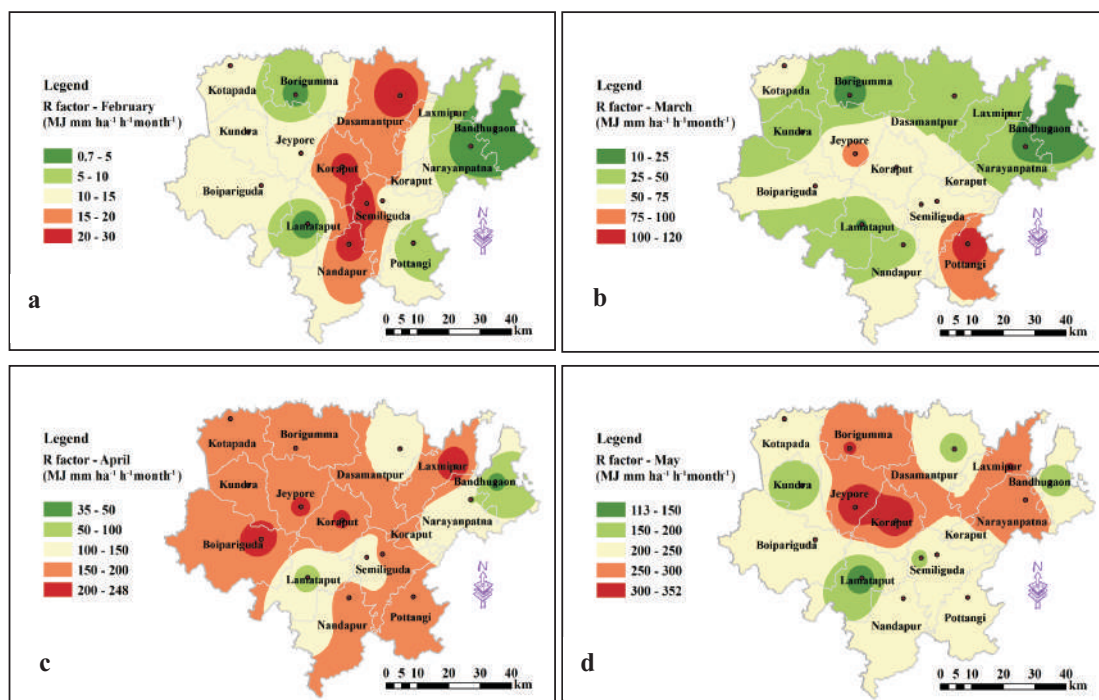


Fig. 3: Spatial distribution of monthly rainfall erosivity in Koraput district, Odisha for February to May

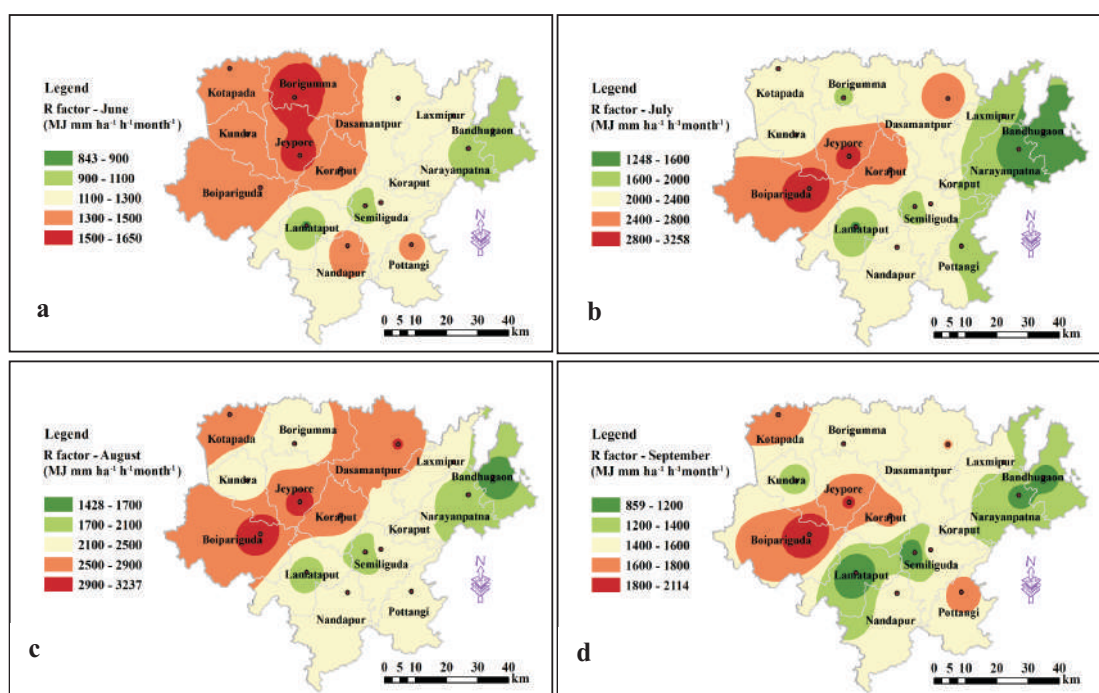


Fig. 4. Spatial distribution of monthly rainfall erosivity in Koraput district, Odisha for June to September

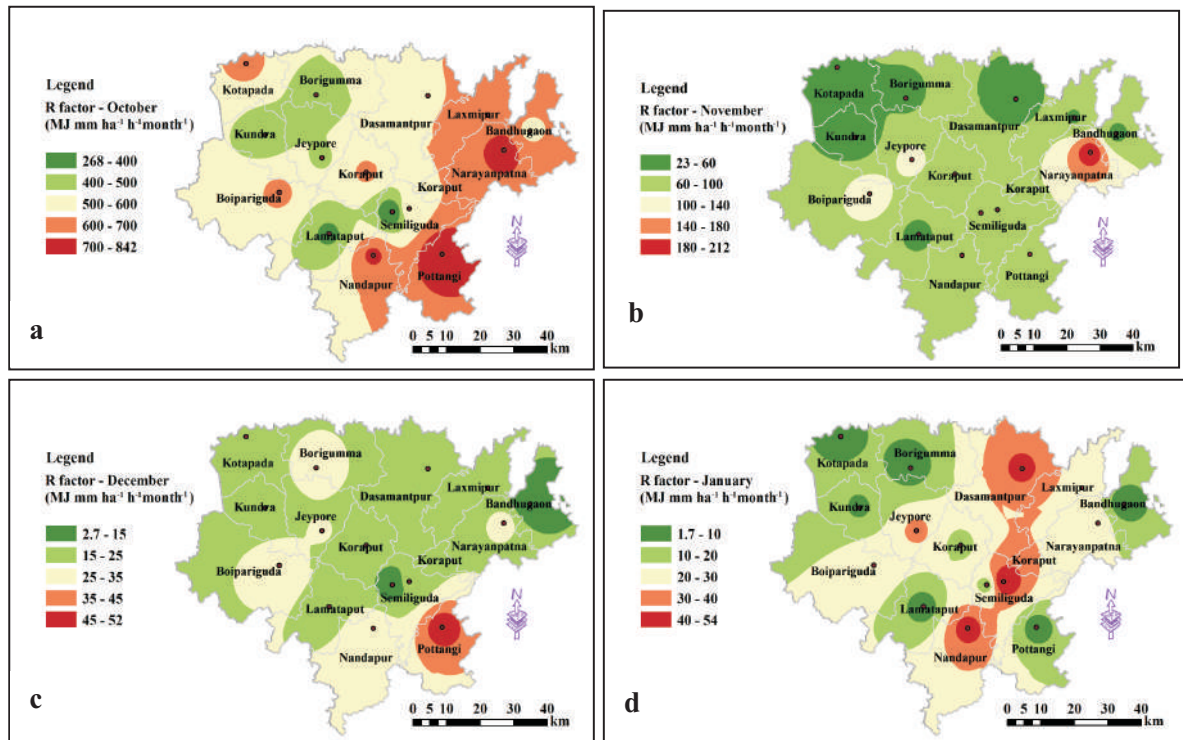


Fig. 5. Spatial distribution of monthly rainfall erosivity in Koraput district, Odisha for October to January

3.3 Rainfall erosivity and soil erosion

Rainfall erosivity is a key factor in soil erosion, describing the potential of rain to cause erosion based on the amount and intensity of rainfall. High erosivity values such as those recorded in the study area, often correlate with severe soil erosion, particularly in regions with intense monsoonal rainfall (Panagos *et al.* 2015). The intense rainfall during the monsoon season exacerbates the erosive impact on the soil, leading to increased runoff and sediment displacement. The study area experiences substantial annual rainfall, ranging between 980 and 1843 mm over approximately 70 days (Dash *et al.* 2019). The mean annual rainfall erosivity, measured at 8367 MJ mm ha⁻¹ h⁻¹ yr⁻¹, indicates significant potential for soil erosion, particularly during the monsoon season from June to September. This seasonal concentration of intense rainfall heightens the risk of soil erosion, making strategic soil and water conservation measures critical for maintaining soil health and agricultural productivity. Effective soil and water conservation strategies are essential to mitigate

the effects of high rainfall erosivity. These measures are typically categorized into biological, mechanical, and drainage line treatments, each addressing different aspects of erosion control.

Biological measures involve the use of vegetation to protect soil. Techniques such as contour farming, intercropping, strip cropping, alley cropping, and conservation tillage have proven effective in reducing soil erosion on slopes less than 5% (Jakhar *et al.* 2015; Adhikary *et al.* 2017; Dash *et al.* 2023). For example contour farming is the cultivating along contour lines helps in slowing runoff velocity, increasing water infiltration and reducing soil erosion; intercropping is the combining crops such as finger millet with pigeon pea (6:2), or maize with cowpea (2:2), can improve soil structure and reduce erosion by providing ground cover and conservation tillage is the minimizing soil disturbance through no-till or reduced-till practices helps maintain soil structure and organic matter, reducing erosion.

Mechanical measures involve construction of physical structures to control water flow and prevent soil

displacement. In areas with slopes between 8-10%, structures like contour bunds, field bunds, and stone bunds are effective (Madhu *et al.* 2016; Dash *et al.* 2017). For instance, the contour bunds are the embankments constructed along contours reduce runoff velocity and capture soil particles; stone bunds are the placement stones in strategic locations help in stabilizing soil and reduce erosion in fields. In degraded, non-arable lands, staggered contour trenching and diversion drains are recommended to manage runoff. Additionally, structures such as loose boulder check dams, gabions, and RCC check dams in streams provide effective erosion control by slowing water flow and trapping sediment.

Agroforestry integrates trees and shrubs with crops and livestock, enhancing soil conservation and productivity. Promoting species such as *Shorea robusta*, *Pterocarpus marsupium*, and *Tectona grandis* alongside field crops like paddy, millets, maize and legumes can reduce soil erosion (Dash *et al.* 2023). Crops like ginger, turmeric, pineapple, black pepper, and arrowroot thrive under shade, complementing agroforestry systems. Implementing a combination of biological, mechanical, and agroforestry measures tailored to specific land conditions can significantly mitigate soil erosion caused by intense rainfall. By adopting these practices, the adverse effects of rainfall-induced erosion can be minimized, promoting soil health and sustainable agricultural productivity. These strategies not only protect the soil but also enhance water management and biodiversity, contributing to long-term environmental sustainability.

4. Conclusions

The spatial maps of monthly rainfall erosivity are crucial for assessing soil erosion risk and implementing suitable soil and water conservation measures. In this study, the mean annual rainfall erosivity factor in Koraput was calculated to be $8364.7 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ yr}^{-1}$. The detailed spatial analysis indicated that the highest monthly rainfall erosivity values were observed in Boipariguda, Dasamantapur, Jeypore and the Koraput blocks. Conversely, lower

erosivity values were noted in the northeastern part of the district, including Bandhuguan, parts of Laxmipur, and Narayanpatna. These spatial variations in rainfall erosivity highlight the importance of localised soil conservation strategies tailored to the specific erosion risks of different areas within the district.

The generated spatio-temporal maps of rainfall erosivity serve as vital resources for policymakers and land managers. These maps can identify soil erosion hotspots and periods of highest soil erosion risk, enabling the formulation of precise and effective soil and water conservation strategies. By focusing conservation efforts on the most vulnerable areas and times, it is possible to mitigate the adverse impacts of soil erosion, thereby protecting natural resources and enhancing sustainable land management practices. The insights gained from this study provide a scientific basis for developing comprehensive soil conservation policies and interventions crucial for the long-term sustainability of the region's agricultural and ecological systems.

References

- Adhikary, P. P., Hombegowda, H. C., Barman, D., Jakhar, P. and Madhu, M. (2017). Soil erosion control and carbon sequestration in shifting cultivated degraded highlands of eastern India: performance of two contour hedgerow systems. *Agroforestry Systems* **91**(4), 757-771.
- Adhikary, P.P. and Dash, Ch. J. (2017). Comparison of deterministic and stochastic methods to predict spatial variation of groundwater depth. *Applied Water Science* **7**, 339-348. DOI 10.1007/s13201-014-0249-8.
- Adhikary, P.P., Madhu, M., Dash Ch J, Sahoo DC, Jakhar P, Naik BS, Hombegowda HC, Naik GB and Dash B (2015) Prioritization of traditional tribal field crops based on RWUE in Koraput district of Odisha. *Indian Journal of Traditional Knowledge* **14**(1), 88-95.
- Ballabio, C., Borrelli, P., Spinoni, J., Meusburger, K., Michaelides, S., Beguería, S., Klik, A., Petan, S., Janeček, M., Olsen, P., Aalto, J., Lakatos, M., Rymaszewicz, A., Dumitrescu, A., Tadić, M.P.,

- Diodato, N., Kostalova, J., Rousseva, S., Banasik, K., Alewell, C. and Panagos, P. (2017). Mapping monthly rainfall erosivity in Europe. *Science of Total Environment* **579**, 1298-1315.
- Brown, L.C. and Foster, G.R. (1987). Storm erosivity using idealized intensity distribution. *Transaction of American Society of Agricultural Engineering* **30**, 379-386.
- Census. (2011). Census of India. New Delhi: Government of India.
- Dash, Ch. J., Das, N.K. and Adhikary, P.P. (2019). Rainfall erosivity and erosivity density in Eastern Ghats highland of east India. *Natural Hazards* **97(2)**, 727-746.
- Dash, Ch. J., Adhikary, P.P., Madhu, M., Sahoo, D.C., Dash, B.K., Naik, G. and Barla, G.W. (2017). Traditional soil and water conservation practices by the tribal farmers in Koraput district of Odisha. *Indian Journal of Soil Conservation* **45(2)**, 227-234.
- Dash, Ch. J., Lenka, J., Hombegowda, H.C., Bishnoi, R., Yadav, P., Mandal, D., Dogra, P., Kumar, G., Kaushal, R., Roy, T., Islam, S. and Madhu, M. (2023). Soil erosion status, priority treatment areas and conservation measures for different districts of Odisha. ICAR-Indian Institute of Soil and Water Conservation, Dehradun, Uttarakhand, India.
- Jakhar, P., Adhikary, P.P., Naik, B.S. and Madhu, M. (2015). Finger millet (*Eleusine coracana*) - groundnut (*Arachis hypogaea*) strip cropping for enhanced productivity and resource conservation in uplands of Eastern Ghats of Odisha. *Indian Journal of Agronomy* **60(3)**, 365-371.
- Jinger, D., Kaushal, R., Kumar, R., Paramesh, V., Verma, A., Shukla, M., Chavan, S.B., Kakade, V., Dobhal, S., Uthappa, A.R., Roy, T., Singhal, V., Madegowda, M., Kumar, D., Khatri, P., Dinesh, D., Singh, G., Singh, A.K., Nath, A.J., Joshi, N., Joshi, E. and Kumawat, S. (2023). Degraded land rehabilitation through agroforestry in India: Achievements, current understanding, and future perspectives. *Frontier in Ecological Evolution* **11**, 1088796. doi: 10.3389/fevo.2023.
- Kravchenko, A. and Bullock, D.G. (1999). A comparative study of interpolation methods for mapping soil properties. *Agronomy Journal* **91**, 393-400.
- Lee, J.H. and Heo, J.H. (2011). Evaluation of estimation methods for rainfall erosivity based on annual precipitation in Korea. *Journal of Hydrology* **409**, 30-48.
- Madhu, M., Naik, B.S., Jakhar, P., Hombegowda, H.C., Adhikary, P.P., Gore, K.P., Barman, D. and Naik, G.B. (2016). Comprehensive impact assessment of resource conservation measures in watershed of eastern region of India. *Journal of Environmental Biology* **37**, 391-398.
- Mueller, T.G., Pierce, F.J., Schabenberger, O. and Warncke, D.D. (2001). Map quality for site-specific fertility management. *Soil Science Society of American Journal* **65(5)**, 1547-1558.
- Naik, B.S., Paul, J.C., Panigrahi, B. and Sahoo, B.C. (2015). Soil erosion assessment from farming lands of Eastern Ghats region of Odisha. *Indian Journal of Soil Conservation* **43(1)**, 33-37.
- Panagos, P., Ballabio, C., Borrelli, P., Meusburger, K., Klik, A., Rousseva, S., Tadić, M.P., Michaelides, S., Hrabalíková, M., Olsen, P., Aalto, J., Lakatos, M., Rymaszewicz, A., Dumitrescu, A., Beguería, S. and Alewell, C. (2015). Rainfall erosivity in Europe. *Science of Total Environment* **511**, 801-814.
- Singh, J. and Singh, O. (2020). Assessing rainfall erosivity and erosivity density over a western Himalayan catchment, India. *Journal of Earth System Science* **129**, 97. 10.1007/s12040-020-1362-8.