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Farm Pond Designs for Moderate to High Rainfall Zone of Marathwada Region based on Rainfall-Runoff Relationship

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Abstract : Accurately designed farm ponds enhance water storage and agricultural resilience during Marathwada's dry spells and variable monsoon patterns. In this study, runoff was estimated using the SCS Curve Number method, which considered various parameters such as soil type and vegetation. The rainfall-runoff relationship was analysed to facilitate the planning of small water harvesting structures, like farm ponds. The runoff potential was found to be 31.69% of the rainfall, indicating significant opportunities for rainwater harvesting and the construction of additional site-specific structures. The established rainfall-runoff relationship is represented by the equation $Y = 0.608X – 209.2$, with an R^2 value of 0.9575. This linear relationship will aid in predicting runoff for any rainfall event in the area, allowing for a more accurate determination of rainwater harvesting potential and its reuse for enhancing the productivity of various rainfed crops. Given the climatic variations in the last decade—particularly concerning rainfall intensity, duration, and frequency—there is a need to redesign farm pond sizes in Marathwada's rain-scarce zones for effective implementation of the farm pond program. The recommended farm pond sizes include storage capacities of 939 cum, 1,677 cum, and 2,811 cum for catchment areas of 1 ha, 2 ha, and 3 ha, respectively. Based on these storage capacities, square-shaped farm ponds with top dimensions of 22 x 22 m, 28 x 28 m, and 35 x 35 m, a depth of 3 m, and a trapezoidal side slope of 1.5:1 are proposed for the State Department of Agriculture's implementation.

Key words: *Curve number, farm pond, micro- catchment, rainfall, runoff*

Introduction

Rainfed agriculture supports 40 percent of the global population and contributes 44 percent to India's total food production (Singh and Singh, 2017). The fate of rainfed agriculture depends on the quantity and distribution of monsoon rains, making rainwater conservation crucial for stabilizing and enhancing productivity. Droughts, occurring frequently across different parts of the country, further reduce total agricultural output. Farmers in dry regions will be the most affected by climate change in the future, necessitating diverse coping strategies for adaptation.

Runoff estimation is vital for designing water harvesting structures, as these play an important role in managing water resources efficiently. Runoff, a key hydrologic variable, is influenced largely by rainfall intensity (Kundzewicz and Arnell, 2008). Other factors, such as rainfall duration, intensity, and aerial distribution, also affect the rate and volume of runoff. Catchment characteristics like slope, shape, size, soil cover, and rainfall duration directly influence peak flow and runoff

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volume (Chandler, 1998). Over the past decade, climatic variations have led to uneven rainfall and runoff distribution, affecting agricultural productivity.

The Marathwada region of Maharashtra is traditionally drought-prone, with annual rainfall ranging from 500 to 1100 mm, and around 20 percent of the area is classified as moderate to high rainfall (900 to 1100 mm/year) zones. Rainfall in this region is often erratic, and severe droughts frequently occur. Crop productivity declines due to both insufficient rainfall and uneven distribution, which can cause moisture stress at critical growth stages during dry spells, particularly in July and August. These conditions underscore the importance of rainwater harvesting for ensuring sustainable crop production.

Rainwater harvesting structures can help store water for agricultural use during dry periods, contributing to increased resilience in crop production. Around 20 per cent of Marathwada falls within the moderate to high rainfall zone (Bawankar et al., 2012). However, the region still experiences two to three prolonged dry spells during the crop growth period. These dry spells significantly reduce crop productivity and adversely affect farmers′ socio-economic conditions. The average productivity of kharif crops fluctuates based on monsoon behaviour.

To address this challenge, properly designed farm ponds based on runoff potential are essential for efficient water storage and sustainable crop production. By capturing and storing rainwater, farmers can better manage water resources and reduce their vulnerability to climate-related risks.

Material and methods

For estimating the runoff potential, daily rainfall data for the moderate to high rainfall zone (Nanded station) from 2011 to 2021 was collected from the Meteorological Observatory at the All India Coordinated Research Project on Agro-Meteorology (AICRPAM), VNMKV, Parbhani (Latitude: 19.1383° N, Longitude: 77.3209° E). The daily runoff for each runoff-producing rainfall event was estimated using the Soil Conservation Service (SCS) Curve Number (CN) method. The rainfall and runoff data were analysed and grouped fortnightly to understand runoff potential over time.

The SCS Curve Number technique is based on the recharge capacity of the watershed, which depends on antecedent moisture conditions and the physical characteristics ofthe watershed. Antecedent Moisture Condition (AMC) serves as an index of watershed wetness (Ponce and Hawkins, 1996). In this study, the Hydrological Soil Group (HSG, which plays a critical role in runoff production) of the area was considered as Group "D", representing soils with low infiltration rates. The selection of curve numbers was based on various factors such as hydrologic soil cover, land use, treatment or cultivation practices, hydrological conditions, and the HSG of the area.

Using the standard equations for runoff estimation in black soil regions, the SCS Curve Number technique was applied to determine runoff potential. Available maps of land use/land cover and HSG were used to estimate the area of each land class. Curve numbers suitable for each land use and HSG were assigned, and the weighted curve number for the watershed was calculated. This weighted curve number was then used to estimate the runoff potential of the study area. Studies by Amutha and Porchelvan (2009), Bansode and Patil (2014), Bhura et al. (2015), and Mishra et al. (2005) have successfully utilised the SCS Curve Number method for similar runoff estimations, and the same methodology was applied here.

The fortnightly runoff volume was calculated based on the runoff potential of the standard catchment area. Factors like pan evaporation and seepage rates through the soil strata were also considered to determine the cumulative runoff potential for farm ponds. With these factors in mind, the runoff volume that could be harvested was estimated, and the sizes of farm ponds suitable for various catchment areas were calculated accordingly.

This approach provides an effective framework for estimating runoff potential and designing water harvesting structures in regions like Nanded, where rainfall is often moderate to high. This method can help farmers manage water resources efficiently by proper designing of farm ponds, ensuring better water availability for agricultural purposes during dry spells.

Results and Discussion

Estimation of Cure Numbers

CN values were estimated based on the hydrologic soil group, the average slope of the land and the land use pattern of the area for the moderate to high rainfall zone of the Marathwada region. The weighted values of curve numbers for three AMC conditions were calculated usingthe USDA SCS-CN method. The hydrologic soil group for the region was observed as 'D' with a slope range of 0.5 to 3.0 %. The weighted curve numbers were calculated as 79, 91 and 97 for AMC-I,AMC-II and AMC-III, respectively.

Estimation of runoff volume

The daily surface runoff was estimated, thereby establishing the yearly runoff data for the moderate to high rainfall zone of the Marathwada region (Table 1). The average runoff was calculated, and the maximum runoff year was also noted.

Table 1: Yearly rainfall, runoff, % runoff and runoff coefficientfor moderate to high rainfall zone

Year	Annual Rainfall (mm)	Rainfall (mm)	Runoff (mm)	Runoff (%)	Runoff coefficient
2011	708.1	697.1	205.3	29.45	0.294
2012	662.7	662.7	122.2	18.43	0.184
2013	1111.9	1091.6	414.2	37.94	0.379
2014	436.5	434.0	99.0	22.81	0.228
2015	599.0	465.2	71.0	15.26	0.152
2016	1124.8	1094	479.7	43.84	0.438
2017	641.8	633.6	161.5	25.48	0.254
2018	799.5	749.8	272.8	36.38	0.363
2019	1027.1	1007.7	344.0	34.13	0.341
2020	924.7	918.9	368.9	40.14	0.401
2021	1293.4	1230.3	550.0	44.70	0.447
Average	848.13	816.8	280.78	31.69	0.316
Maximum	1293.4	1230.3	550.00	44.70	0.44.0

The average rainfall causing runoff was found to be 816.8 mm, which generated a mean runoff of 280.78 mm, i.e. 31.69 per cent. The maximum rainfall causing runoff was recorded as 1293.4 mm in the year 2021 and had a runoff potential of 550 mm (44.70 per cent). The data related to extreme/ heavy rainfall events for the moderate to heavy rainfall zone during the years 2011 to 2021 (Table 2).

Table 2 : Extreme/heavy rainfall events in the moderate to heavy rainfall zone of Marathwada Region

Years	July		August		September	
	Date	Rainfall, mm	Date	Rainfall, mm	Date	Rainfall, mm
2013	17.7.13	54.1	1.8.13	56.2	-	-
2016	12.7.16	77.2	24.8.16	50.8	-	-
2017	-	-	20.8.17	97.4	-	-
2018	-	-	21.8.18	78.1	-	-
2019	-	-	3.8.19	56.9	1.9.19	50.7
2021	12.7.21	57.1	-	-	8.9.21	62.2
	22.7.21	62.8	-	-	9.9.21	54.3
	-	-	-	-	28.9.21	90.4

Out of the 11-year period, heavy rainfall events were observed in 6 years, which generated maximum runoff.

Rainfall-runoff relationship for moderate to high rainfall zone of Marathwada region

Vinithra and Yeshodha (2013) developed a rainfall-runoff model using SCS-CN method as a case study of Krishnagiri district, Tamil Nadu state. Similarly, Satheesh Kumar et al. (2017) conducted a study on a rainfall-runoff relationship using SCS–CN and GIS approach for the Pappiredipatti watershed of the Vaniyar sub-basin, South India.

In the present study, arainfall-runoff relationship was obtained to determine the runoff corresponding to any rainfall occurring in the study area. The relationship was found to be linear and is expressed as $Y = 0.608X - 209.2$ with the R^2 value of 0.96.

Design of Farm ponds for moderate to high rainfall zone of Marathwada region

Farm ponds were designed based on the rainfall-runoff relationship expected evaporation and seepage losses during the monsoon season and also according to the catchment areas of 1 ha, 2 haand 3 ha, and the average size of land holding of the farmers of the region. The size and storage capacity of farm ponds depend on runoff potential from the catchment area, and accordingly, the farm ponds were designed for all three stations, *viz.* Aurangabad, Parbhani and Nanded stations, respectively (Table 3).

The runoff volume was estimated by the end of each fortnight for 1ha, 2 ha and 3 ha catchment areas, respectively. Dependable run off from the catchment areas was considered as 80%, and adding current rainfall in the pond and then subtracting the expected storage losses (Seepage and evaporation), fortnightly runoff and cumulative runoff volumes, expected to be harvested, were estimated. Based on the expected runoff volume, the tentative size of the farm pond was worked out. According to the top surface area of the farm pond and average evaporation rate, the water loss during the fortnight was worked out. Similarly, seepage losses were estimated based on the size of the pond. Pond evaporation losses are calculated by multiplying the surface area of ponded water with open pan evaporation of that fortnight with a pan coefficient of 0.70. The seepage rate is taken as constant as 20 mm/day, and seepage losses are calculated by multiplying the seepage rate by the surface area of ponded water (Tables 4 ,5, and 6).

Table 3 : Year-wise Fortnightly rainfall-runoff for moderate to high rainfall zone of Marathwada region

Year	June				July				August				September				October			
	1-15		16-30		1-15		16-31		1-15		16-31		1-15		16-31		1-15		16-31	
	Rainfall	Runoff	Rain fall	Run off	Rain fall	Runo ff	Rainf all	`Run off	Rainf all	Run off	Rain fall	Run off	Rain fall	Runo ff	Rain fall	Run off	Rain fall	Run off	Rain fall	`Run off
2011	46.4	0	46.7	5	140.	53	70.1	9	104	49	189	82	54.9	4	35.4	2.5	9.3	0	0	0
2012	7.6	0	101	31	78.7	8	140.	39.1	48.6	0	107	18.	86.6	18.5	39.1	3.5	52.8	3	0	0
2013	120.8	27	82.9	19.5	148	47	279	173	161	91	57.7	19	45.7	4	82.8	15	93	16	19.7	2
2014	11.7	0	17.6	0	44.9	0	45.9	0	43.7	0	151	63	96.2	36	16.5	0	1.6	0	4.4	0
2015	66.2	9	90.3	34	8	0	43.7	0	85.1	3	44.4	0	69.9	0	48	25	9.5	0	0	0
2016	49.9	3	164.6	68.5	178.	85	173.	70	52.6	23	49.8	17	91.9	40	209	108	123.9	65	0	0
2017	77.6	7	90.1	22	30.1	0	78.3	30	44.7	2.5	188.	93	33.5	0	31.8	2	47.2	5	11.8	0
2018	162.5	76	79.9	6	116	30	46.5	5	50.7	6	250	149	18.4	0	24.2	0	0.1	0	0.3	0
2019	14.3	0	77.5	6.2	65.6	7.8	159	54	168	89	57.2	12	144	60	135	47	39.6	2	146.2	61.5
2020	81.2	3	64.8	4	131.	51	98.6	5	103	5	100	34	98.6	23	166	77	62.9	2	10.7	0
2021	142.8	50	82.3	18	205	121	182	107	13	0	168.	60	197.	109	177	84	26.2	1	35.3	0

Table 4 : Design ofFarm pond for 1 ha catchment area for moderate to high rainfall Zone of Marathwada region

Month	Duration	Rainfall (mm)	Runoff (mm)	Runoff volume (m^3) for 1 ha area)	Dependable runoff volume (80%) (m^3)	Rainfall In pond (m^3)	Total (m^3)	Expected Evaporation from Pond (m^3)	Expected Seepage Losses from pond (m^3)	Expected Run. Volume (m^3)	Expected Cumulative Runoff volume (m^3)	Remark
June	7-15	71	15.90	159	127	34.36	161.36	28.11	23.78	109.47	109.47	
	16-30	81.60	19.47	194	155	39.49	194.49	48.12	34.70	111.67	221.14	1st
July	1-15	104.35	36.61	366	292	50.50	342.5	39.71	30.20	272.59	493.73	filling
	16-31	119.79	44.78	447	357	57.97	414.97	38.12	33.00	343.85	837.58	of farm
Aug	1-15	79.70	24.40	244	195	38.57	233.57	35.42	28.70	169.45	1007.03	pond
	16-31	124.16	49.88	498	398	60.09	458.09	39.01	34.40	384.68	1391.71	2nd
Sept.	1-15	85.2	26.77	267	213	41.23	254.23	36.10	31.60	186.53	1578.24	filling
	16-31	87.86	33.15	331	264	42.52	306.52	35.23	39.50	231.79	1810.03	of farm
Oct.	1-15	42.37	8.54	854	683	20.50	703.5	38.72	49.70	615.08	2425.11	pond
	16-31	20.76	5.77	577	461	10.04	471.04	44.67	54.0	372.37	2797.48	3rd
												filling
												of farm
												pond

Size of farm pond
Top – 22m x 22m
Bottom – 13mx13m
Depth – 3 m
Side slope – 1.5:1
Volume of storage: 939 Cum

Area irrigated = 1.6 ha
No. of irrigation = 2
Depth of irrigation = 5 cm

Table 5: Design ofFarm pond for 2 ha catchment area for moderate to high rainfall Zone of Marathwada region

Month	Duration	Rainfall (mm)	Runoff (mm)	Runoff volume (m^3)for 2ha area)	Dependable runoff volume (80%) (m^3)	Rainfall In pond (m^3)	Total (m^3)	Expected Evaporation from Pond (m^3)	Expected Seepage Losses from pond (m^3)	Run. Volume At the end of runoff (m^3)	Cumulative Runoff volume (m^3)	Remark
June	7-15	71	15.90	318	254.4	55.66	310.06	45.54	32.70	231.82	231.82	
	16-30	81.60	19.47	388	310.4	63.97	374.37	77.96	46.50	249.91	481.73	1st filling of
July	1-15	104.35	36.61	732	585.6	82.81	668.41	64.33	44.10	559.98	1041.71	farm pond
	16-31	119.79	44.78	894	715.2	93.91	809.11	38.12	43.50	727.49	1769.2	
Aug.	1-15	79.70	24.40	488	390.4	62.48	452.88	57.38	42.60	352.9	2122.1	2nd filling of
	16-31	124.16	49.88	996	796.8	97.34	894.14	63.19	46.50	784.45	2906.55	farm pond
Sept.	1-15	85.2	26.77	534	427.2	66.79	493.99	58.48	46.60	388.91	3295.46	
	16-31	87.86	33.15	662	529.6	68.88	598.48	58.69	52.50	487.29	3782.75	
Oct.	1-15	42.37	8.54	1708	1366.4	33.21	1399.61	62.72	60.40	1276.49	5059.24	3rd filling of
	16-31	20.76	5.77	1154	923.2	16.27	939.47	72.36	64.20	802.91	5862.15	farm pond

Size of farm pond
Top – 28 m x 28 m
Bottom – 19 mx19 m
Depth – 3 m
Side slope – 1.5:1
Volume of storage: 1677 Cum

Area irrigated = 2.8 ha
No. of irrigation = 2
epth of irrigation = 5 cm

Table 6: Farm pond design for 3 ha catchment area for moderate to high rainfall Zone of Marathwada region

Month	Duration	Rainfall (mm)	Runoff (mm)	Runoff volume (m^3)for 3ha area)	Dependable runoff volume (80%) (m^3)	Rainfall In pond (m^3)	Total (m^3)	Expected Evaporation from Pond (m^3)	Expected Seepage Losses from pond (m^3)	Run. Volume At the end of runoff (m^3)	Cumulative Runoff volume (m^3)	Remark
June	7-15	71	15.90	477	381.6	86.97	468.57	71.16	46.20	351.21	351.21	
	16-30	81.60	19.47	582	465.6	99.96	565.56	115.68	66.70	383.18	734.39	1st filling of
July	1-15	104.35	36.61	1098	878.4	127.82	1006.22	100.52	59.20	846.5	1580.89	farm pond
	16-31	119.79	44.78	1341	1072.8	146.74	1219.54	96.49	63.00	1060.05	2640.94	
Aug.	1-15	79.70	24.40	732	585.6	97.63	683.23	89.67	55.50	538.06	3179.00	2nd filling of
	16-31	124.16	49.88	1494	1195.2	152.09	1347.29	98.73	64.50	1184.06	4363.06	farm pond
Sept.	1-15	85.2	26.77	801	640.8	104.37	745.17	91.38	59.60	594.19	4957.25	
	16-31	87.86	33.15	993	794.4	107.62	902.02	91.71	72.50	737.81	5695.06	
Oct.	1-15	42.37	8.54	2562	2049.6	51.90	2101.5	98	89.70	1913.8	7608.86	3rd filling of
	16-31	20.76	5.77	1731	1384.8	25.43	1410.23	113.06	95.00	1202.17	8811.03	farm pond

Size of farm pond
Top – 35m x 35m
Bottom – 26mx26m
Depth – 3 m
Side slope – 1.5:1
Volume of storage: 2811 Cum.

Area irrigated = 2.25 ha
No. of irrigation = 2
Depth of irrigation = 5 cm

Based on design parameters, 1007.03 cum, 1769.2 cum and 2640.39 cum of runoff volume will be expected to be harvestedfor 1 ha, 2 ha and 3 ha catchment areas, respectively. Accordingly, the farm ponds of capacity 939 cum, 1677 cum and 2811 cumwere designed for 1 ha, 2 ha and 3 ha catchment areas, respectively (Table 7).

Table 7: Farm Pond sizes for moderate to high rainfall zone of Marathwada region

Catchment Area, ha	Top Size of pond (m x m)	Bottom Size of pond (m x m)	Side slope	Depth of farm pond (m)	Capacity of farm pond (Cum)	Area under 2 irrigation of 5 cm depth (ha)	Area irrigated of catchment area (%)	Catchment Area under pond construction(%)
1	22 x 22	13 x 13	1.5: 1	3	939	1.60	75	4.84
2	28 x 28	19 x 19	1.5: 1	3	1677	2.14	75	3.92
3	35 x 35	26 x 26	1.5: 1	3	2811	4.22	75	4.08

If runoff is harvested, the stored water can be used for protective irrigation during dry spells of the *kharif* season. For normal monsoon season, the farm ponds would get refilled three times before the withdrawal of monsoon and this stored water can be used to provide supplemental irrigation to *rabi* crops for production enhancement.

Conclusion

The relationship between rainfall and runoff proved to be the most valuable information for designing farm ponds as rainwater harvesting structures. The runoff potential for the moderate to high rainfall zone of the Marathwada region was found to be 31.7 %. A linear relationship between rainfall and runoff was developed to estimate the runoff potential for the study area. For moderate to high rainfall zones of the Marathwada region, farm ponds of 939 cum, 1677 cum and 2811 cum storage capacities were designed for 1 ha, 2 ha and 3 ha catchment areas, respectively.

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

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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 t ha^{-1} 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 t ha^{-1} 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 km², situated between 81° 05′ to 83° 05′ East longitude and 18° 04′ to 19° 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 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*).

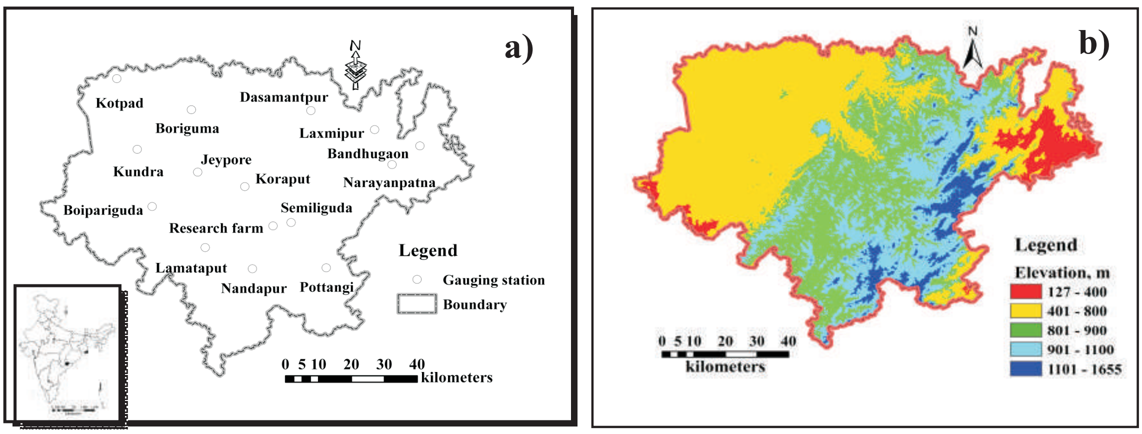

Fig. 1. Map of study area showing a) Rain gauge stations b) Elevation variation

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.

$$KE = 0.29[1 - 0.72\exp(-0.05i)] \quad \text{(1)}$$

where *KE* is the kinetic energy of a single rainfall event (MJ mm^{-1} 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 (I30, mm h-1) was determined, and the R-factor was estimated by multiplying kinetic energy with I_{30}. The daily rainfall erosivity factor (MJ mm ha^{-1} h^{-1} day^{-1}) was calculated by taking the sum of all by single event R-factor values. Similarly, monthly R-factor (MJ mm ha^{-1} h^{-1} month^{-1}) and annual erosivity factor (MJ mm ha^{-1} h^{-1} 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.

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

Where x_i is the ith 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

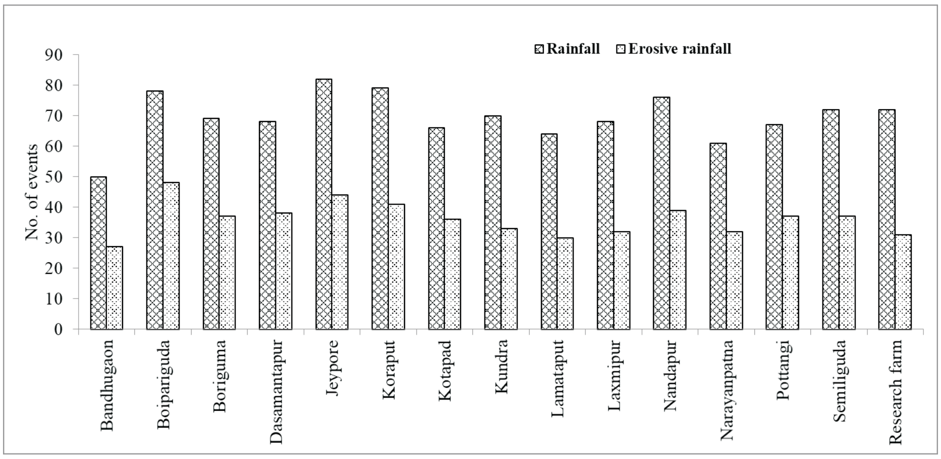

Fig. 2: Block wise distribution of rainfall and erosive rainfall event

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 Bandhugoan (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 (MJ mm ha^{-1} h^{-1} 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 MJ mm ha^{-1} h^{-1} 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 MJ mm ha^{-1} h^{-1} in February and increasing to 237.5 MJ mm ha^{-1} 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 MJ mm ha^{-1} h^{-1} month^{-1}, 28.14 %) followed by July (2122.5 MJ mm ha^{-1} h^{-1} month^{-1}, 25.4 %), September (1470.9 MJ mm ha^{-1} h^{-1} month^{-1}, 17.6%), and June (1267.0 MJ mm ha^{-1} h^{-1} 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 MJ mm ha^{-1} h^{-1} month^{-1}) followed by January (0.3 MJ mm ha^{-1} hr^{-1} month^{-1}) and December (0.3 MJ mm ha^{-1} h^{-1} 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 MJ mm ha^{-1} h^{-1} month^{-1} (Fig. 3). Bandhugoan, 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 MJ mm ha^{-1} h^{-1} month^{-1}), having higher values of rainfall erosivity in Pottangi, Semilguda, 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 MJ mm ha^{-1} h^{-1} 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 MJ mm ha^{-1} h^{-1} month^{-1}), August (2500 - 3237 MJ mm ha^{-1} h^{-1} month^{-1}) and September (1600 – 2114 MJ mm ha^{-1} h^{-1} 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 Bandhugoan, part of Laxmipur and Narayanpatna. The higher erosivity values during October (268-842 MJ mm ha^{-1} h^{-1} month^{-1}), November (23-212 MJ mm ha^{-1} h^{-1} month^{-1}), and December (3-52 MJ mm ha^{-1} h^{-1} 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.

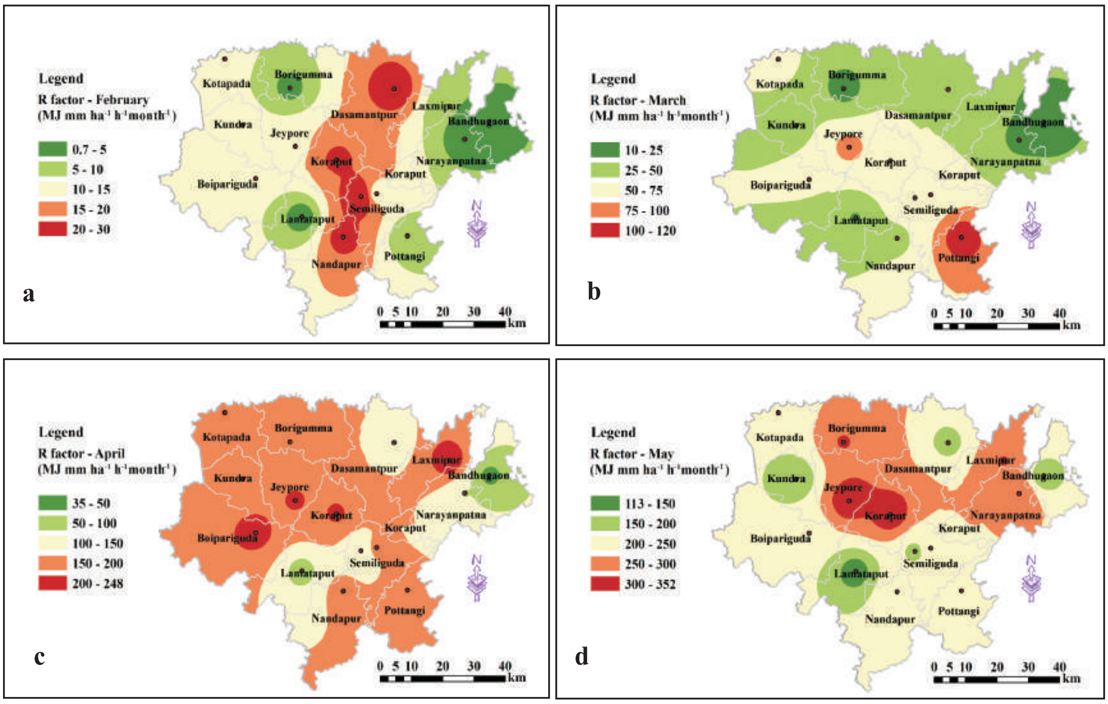

Fig. 3: Spatial distribution of monthly rainfall erosivity in Koraput district, Odisha for February to May

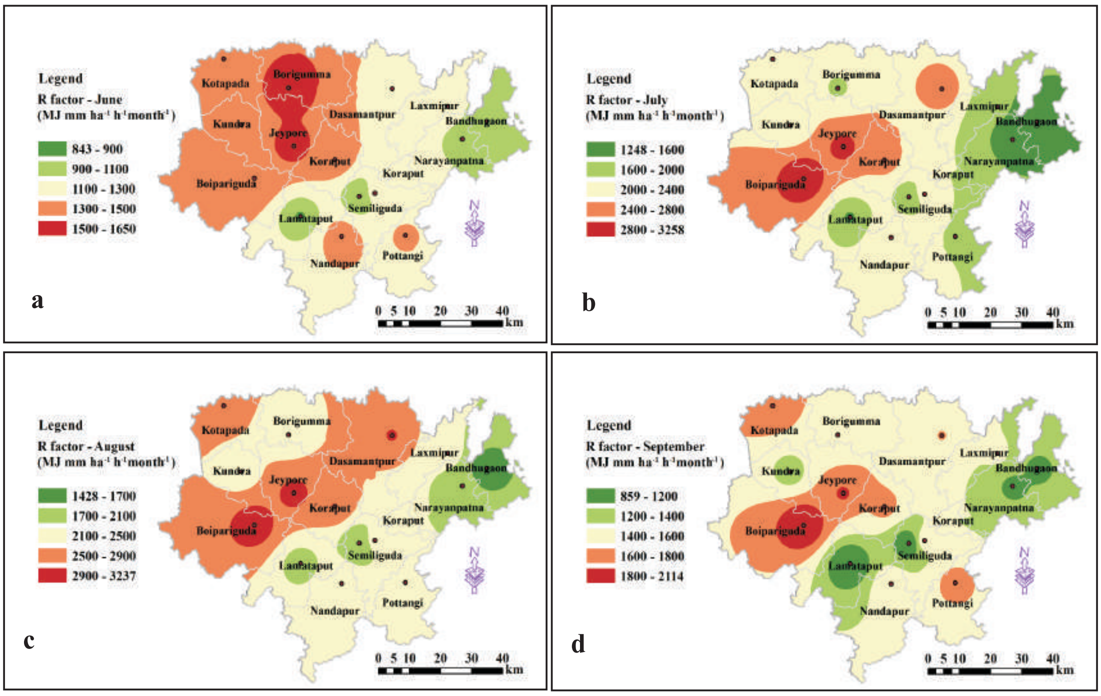

Fig. 4. Spatial distribution of monthly rainfall erosivity in Koraput district, Odisha for June to September

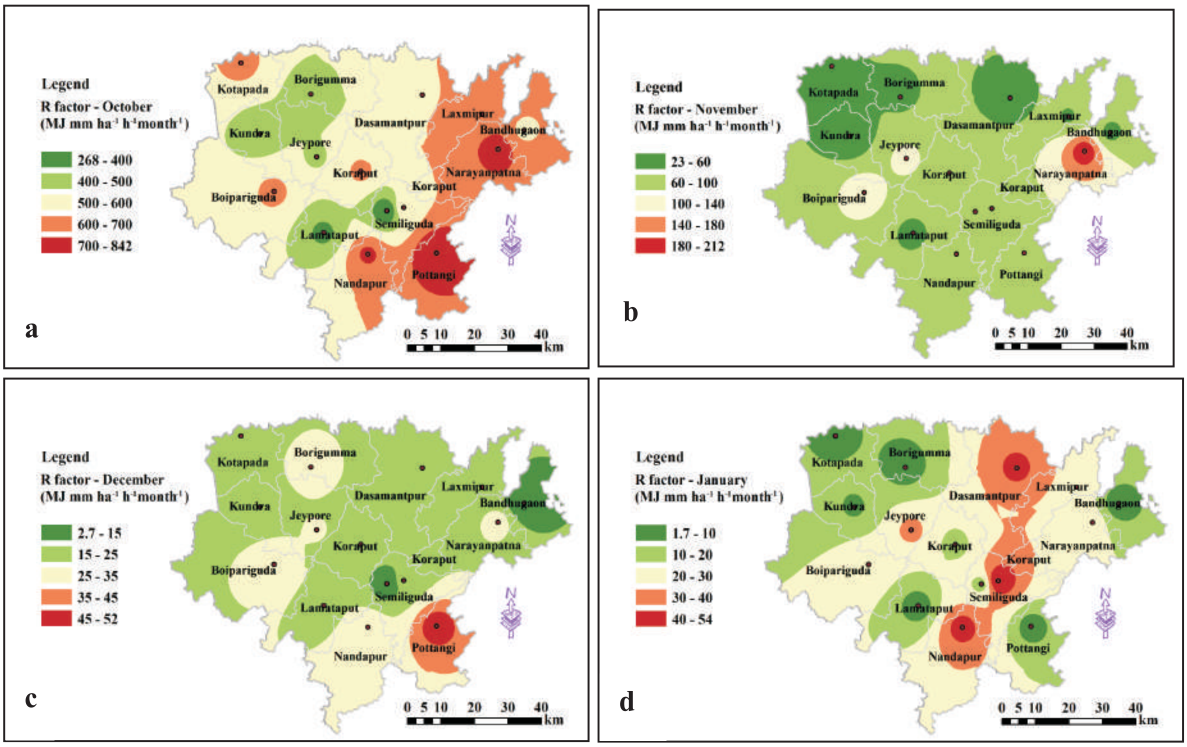

Fig. 5. Spatial distribution of monthly rainfall erosivity in Koraput district, Odisha for October to January

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 MJ mm ha^{-1} h^{-1} 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 Bandhugoan, 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.

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