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Rainfall variability and trend analysis for selected districts of Chhattisgarh plain zone

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Abstract

Rainfall, the key driver of agriculture in Central India's rainfed regions, was analyzed for seven districts of the Chhattisgarh Plain Zone (Bemetara, Bilaspur, Janjgir-Champa, Kabirdham, Korba, Mungeli, and Raigarh) using 24 years (2001–2024) of gridded data. Mean annual rainfall ranged from 1197.6 mm to 1387.7 mm, with Raigarh district recording the highest rainfall and rainy days, and Kabirdham district showing the highest variability (24.1%). The South-West monsoon (June–September) contributed over 80% of annual rainfall. Trend analysis (Mann–Kendall test) showed a significant increase at the 95% confidence level in Bemetara and Kabirdham, while other districts had non-significant trends, supporting improved crop planning and water management.

Keywords: Agroclimatic characterization, rainfall variability, Mann-Kendall test

1. Introduction

Rainfall is a key agrometeorological factor controlling crop production, soil moisture, and length of growing period in monsoon-dependent regions like India, where over 50% of the net sown area depends on southwest monsoon rainfall (Gadgil, 2003) ^[5]. Studies by Kumar *et al.* (2010) ^[9], Basistha *et al.* (2013) ^[11], and Guhathakurta *et al.* (2015) ^[6] highlight significant spatial and temporal rainfall variability linked to climate change. Statistical methods such as the Mann–Kendall and Sen's slope estimator are widely used for trend analysis (Mann, 1945; Kendall, 1975; Sen, 1968) ^[10, 8, 12]. In the Chhattisgarh Plain zone, a rainfed, rice-based system receives about 85–90% of its annual rainfall during the southwest monsoon. Variability in monsoon onset, distribution, and withdrawal affects productivity and water availability.

2. Materials and Methods

2.1 Studied Area

Seven districts i.e. Bilaspur, Bemetara, Janjgir-Champa, Korba, Kawardha, Mungeli, Raigarh of the Chhattisgarh Plain zone were selected for the study.

2.1 Weather database

The rainfall data analysis for the selected 7 districts (Bemetara, Bilaspur, Janjgir-Champa, Kabirdham, Korba, Mungeli, and Raigarh) has been done by collecting 24 years (2001-2024) gridded rainfall data from the IMD website at 0.25°×0.25° resolution. Rainy-day analysis was also conducted, assuming that a day with at least 2.5 mm rainfall was a rainy day.

2.2 Statistical analysis

$$\text{Mean } (\mu) = \frac{\text{Sum of all observations}}{\text{Number of observations}}$$

$$\text{Standard deviation } (\sigma) = \sqrt{\frac{\sum (X - \mu)^2}{n - 1}}$$

Coefficient of Variation CV (%) = $\frac{\text{standard deviation}}{\text{mean}} \times 100$

Where X is the actual value of any weather element and ‘n’ is the number of years.

2.3 Trend Analysis

The *S* statistic is calculated as the sum of the signs of the differences between all pairs of data points:

pairs of data points: $S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i)$

Where:

- *n* is the number of data points.
- *x_i* and *x_j* are sequential data values.
- *sgn(x_j - x_i)* is the sign function, calculated as:

$\text{sgn}(x_j - x_i) = \begin{cases} +1 & \text{if}(x_j - x_i) > 0 \\ 0 & \text{if}(x_j - x_i) = 0 \\ -1 & \text{if}(x_j - x_i) < 0 \end{cases}$

2. Variance of *S*(*Var(S)*)

If there are tied ranks in the data, the variance is:

$Var(S) = \frac{1}{18} \left[n(n-1)(2n+5) - \sum_{k=1}^p q_k(q_k-1)(2q_k+5) \right]$

Where,

- *n* is the number of data points.
- *p* is the number of tied groups.
- *q_k* is the number of data points in the *k*-th tied group.

3. Standardized Test Statistic (*Z_{MK}*)

For *n* > 10, the statistic *S* follows a normal distribution:

$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & \text{if } S < 0 \end{cases}$

- A positive *Z_{MK}* indicates an increasing trend.
- A negative *Z_{MK}* indicates a decreasing trend.

3. Results and Discussion

3.1 Annual Rainfall and Rainy Days

The analysis revealed that the selected districts receive moderate to high rainfall. The mean annual rainfall varied from 1197.6 mm to 1387.7 mm (Table 1). Raigarh district recorded the highest mean annual rainfall (1387.7 mm) with the lowest variability (CV = 12.7%), indicating a stable rainfall regime. Conversely, Bilaspur received the lowest mean rainfall (1197.6 mm). Kabirdham district exhibited the highest instability in annual rainfall with a CV of 24.1%. The mean annual number of rainy days ranged between 78 and 89 days. Raigarh recorded the maximum number of rainy days (89), while Bemetara recorded the minimum (78).

Table 1: Characterization of annual rainfall in selected districts (2001-2024)

Districts	Rainfall			Rainy days		
	Mean (mm)	SD (mm)	CV (%)	Mean (Days)	SD (Days)	CV (%)
Bemetara	1237.7	250.4	20.2	78	16	20.9
Bilaspur	1234.2	196.7	15.9	85	12	13.8
JanjgirChampa	1247.4	176.5	14.2	82	11	12.9
Kabirdham	1197.6	288.4	24.1	80	14	17.3
Korba	1300.6	188	14.5	87	12	13.4
Mungeli	1217	195.2	16	85	16	18.4
Raigarh	1387.7	176	12.7	89	13	14.5

3.2 Analysis of the seasonal rainfall and rainy days

Seasonal analysis of rainfall was done for four seasons: SW monsoon (June to September), post-monsoon (October to November), winter (December to February) and summer (March to May) in Table 2 and 3.

3.2.1 Winter Season

Bilaspur district received the maximum (32.8 mm) winter rainfall and Raigarh received the lowest rainfall (21.7mm). Maximum variability was seen in the Bemetara district (133.2%) while the Korba district showed the minimum (87.2%) variability. Almost all the districts had 2-3 days of winter rainy day (Table 3). The highest variability of rainy days in winter was around 96% in the Bemetara district. Korba district had the least variability (79.9%).

3.2.2 Summer Season

Mungeli district received the highest summer rainfall of about 66.6 mm followed by Raigarh district (65.8 mm) and the lowest

rainfall was observed in Korba district (46.9 mm) (Table 2). Variability of the summer season rainfall is highest in Bemetara district (103.8%) and lowest in Bilaspur district (59.7%). Almost all the districts had 6-7 days of rainy days. Bilaspur district had the least variability (63.2%). Maximum variability was observed in the Bemetara district (93%).

3.2.3 South West monsoon season

The South West monsoon contributes more than 80% of the normal annual rainfall (Table 2). Raigarh district had the maximum (1230.3 mm) and Kabirdham district had the minimum (1042.3 mm) of monsoon rainfall. Kabirdham district had the maximum (21.2%) variability while Janjgir-Champa district had the minimum variability (13.4%). The highest number of monsoon rainy days was observed in the Raigarh district (74 days) (Table 3) and the lowest rainy days were observed in the Bemetara district (65 days). Maximum variability was observed in Bemetara district (16.5%), while the lowest variability was found in Raigarh district (12.6%).

3.2.4 Post-monsoon Season

Mungeli district received the highest post-monsoon rainfall (73.5 mm) and Korba district had the lowest rainfall in this season (59 mm) (Table 2). Maximum variability was observed in Mungeli (86.5%) and the minimum was observed in the

Janjgir-Champa district (70.2%). The number of rainy days during the post-monsoon in all the districts varied from 5 to 6 days (Table 3). Maximum variability was seen in Mungeli district (91.7%) while the lowest variability was seen in Raigarh district (56.9%).

Table 2: Characterization of seasonal rainfall in selected districts of Chhattisgarh (2001-2024)

Districts	Winter			Summer			SW (Monsoon)			NE (Post monsoon)		
	Mean (mm)	SD (mm)	CV (%)	Mean (mm)	SD (mm)	CV (%)	Mean (mm)	SD (mm)	CV (%)	Mean (mm)	SD (mm)	CV (%)
Bemetara	24.1	32	133.2	54.6	56.7	103.8	1088.6	185.8	17.1	70.4	59.1	83.9
Bilaspur	32.8	30.6	93.5	57.3	34.2	59.7	1083.9	172.7	15.9	60.2	46	76.3
Janjgir-Champa	22.7	21.2	93.2	52.8	35.9	68	1111.5	148.4	13.4	60.4	42.4	70.2
Kabirdham	27.9	34.4	123.4	54.8	44.4	81	1042.3	220.7	21.2	72.6	60.3	83.1
Korba	25.2	22	87.2	46.9	33.8	72	1169.5	170.7	14.6	59	41.7	70.6
Mungeli	31.5	32.9	104.6	66.6	51.4	77.2	1045.4	145	13.9	73.5	63.6	86.5
Raigarh	21.7	20.9	96.6	65.8	48.1	73	1230.3	154.4	12.6	70	52.6	75.2

Table 3: Characterization of seasonal rainy days in selected districts of Chhattisgarh (2001- 2024)

Districts	Winter			Summer			SW (Monsoon)			NE (Post monsoon)		
	Mean (Days)	SD (Days)	CV (%)	Mean (Days)	SD (Days)	CV (%)	Mean (Days)	SD (Days)	CV (%)	Mean (Days)	SD (Days)	CV (%)
Bemetara	2.2	2.1	96.3	5.7	5.3	93	64.6	10.7	16.6	5.7	4.7	82.9
Bilaspur	3	2.4	80.2	6.4	4	63.2	70.6	10	14.1	5	3.2	65
Janjgir-Champa	2.4	2.1	88.5	5.9	3.8	65.3	68.7	8.6	12.5	5.1	3.4	67.6
Kabirdham	2.6	2.4	92.7	5.6	4.4	78.1	66.3	9.5	14.3	5.6	4	71.6
Korba	2.9	2.3	77.6	5.9	4	67.2	72.8	9.2	12.7	5.2	3.6	68.9
Mungeli	2.8	2.3	81.7	7.3	6	82.3	67.9	8.8	12.9	6.5	5.9	91.7
Raigarh	2.4	2.2	88.8	7.1	5.5	77.4	74.1	10.3	13.8	5.6	3.2	56.9

3.3 Trend Analysis

The Mann-Kendall test results (Table 3) highlighted significant changes in specific districts.

Increasing Trends: Bemetara and Kabirdham districts showed a statistically significant increasing trend in annual rainfall at the 95% confidence level (Z values of 2.356 and 2.108, respectively) (table 4).

Non-Significant Trends: The districts of Bilaspur, Janjgir-Champa, Korba, Mungeli and Raigarh did not exhibit statistically significant trends, suggesting that rainfall in these areas has remained statistically stationary over the study period.

Table 4: Mann-Kendall trend analysis of annual rainfall

Mann-Kendall test						
Sl no.	District name	Test statistic	Critical values			Result
			$\alpha=0.1$	$\alpha=0.05$	$\alpha=0.01$	
1	Bemetara	2.356	1.645	1.96	2.576	S (0.05)
2	Bilaspur	-0.967	1.645	1.96	2.576	NS
3	Janjgir-Champa	0.025	1.645	1.96	2.576	NS
4	Kabirdham	2.108	1.645	1.96	2.576	S (0.05)
5	Korba	0.521	1.645	1.96	2.576	NS
6	Mungeli	0.372	1.645	1.96	2.576	NS
7	Raigarh	-0.786	1.645	1.96	2.576	NS

4. Conclusion

From 2001–2024, Raigarh district recorded the highest rainfall and rainy days, while Kabirdham district had the lowest rainfall and Bemetara district the fewest rainy days. A significant increasing rainfall trend was observed in Bemetara and Kabirdham, whereas other districts showed no significant change. This variability highlights the need for location-specific crop planning, favoring water-intensive crops in stable areas and resilient strategies in more variable regions.

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