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Effect of onset and withdrawal of monsoon on production of major kharif crops in Chhattisgarh state

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Abstract
The agricultural landscape of Chhattisgarh is intrinsically linked to the monsoon, with the majority of Kharif crops dependent on timely and well- distributed rainfall. This research investigates the influence of southwest monsoon onset and withdrawal timings on rainfall distribution and Kharif crop production on Chhattisgarh Plain zone. The study spans the years 2000 to 2022 and evaluates the effects of early, normal, and late monsoon events on the area cultivated under major crops such as rice, maize, and pigeon pea. The data analysis reveals that both the timing and distribution of rainfall, as well as the frequency of rainy days, significantly influence cropping patterns. Normal monsoon onset and withdrawal consistently led to the most favourable outcomes. particularly for rice this is due to optimal sowing periods and moisture availability. Conversely, late onset shortened the growing window and reduced crop areas, while early or delayed withdrawal often disrupted harvest schedules and exposed crops to water stress or disease. Zone-wise observation highlighted varied responses to monsoon behaviour. In the Chhattisgarh Plain, rice benefited most from normal monsoon patterns.

Keywords: Monsoon onset, monsoon withdrawal, duration, kharif crop, Chhattisgarh Plain zone

1. Introduction
The monsoon is a seasonal wind system that brings significant changes in weather patterns, primarily characterized by a shift between wet and dry periods. It is driven by the differential heating of land and ocean, causing large-scale wind reversals. The most well-known example is the Indian monsoon, which occurs due to the temperature contrast between the Indian subcontinent and the surrounding oceans**.** Monsoon onset refers to the beginning of the monsoon season when the southwest monsoon winds first reach a region, bringing significant rainfall. In India, the monsoon typically arrives over the Kerala coast around June 1st, marking the official onset of the Southwest Monsoon. This onset is characterized by a shift in wind patterns, an increase in humidity, and widespread rainfall, which supports the sowing of Kharif crops such as rice, maize, and pulses. The onset progresses northward, covering the entire country over the following weeks. Monsoon withdrawal, on the other hand, marks the retreat of monsoonal rains as the monsoon winds weaken and shift southward. In India, the withdrawal generally begins from north western regions in mid-September and gradually moves southward, exiting completely by mid-October. This phase is associated with decreasing rainfall, clearer skies, and a transition toward the dry season. Early or delayed withdrawal can impact soil moisture levels, affecting the later growth stages and harvesting of Kharif crops. Rainfall is a crucial climatic factor, and disparities in the pattern can directly or indirectly affect agriculture production, human lifestyle, water resources management, and ecosystem function and structure (Kumar & Gautam 2014) [3]. Indian agriculture continues to be a gamble of the vagaries of monsoon, rainfall being most critical because nearly 70% of the net sown area is still rain dependent Narain *et al*. (2006). Annual rainfall of Chhattisgarh is highest over Bastar Plateau (BP) (1345mm) and lowest in Chhattisgarh Plains (CP) (1103mm) while it is intermediary over the Northern Hills Zone (NHZ) (1270mm). There is a large variability in rainfall across the district with highest being in Bastar (1412mm) (Chaudhary 2015) [1].

2. Materials and Methods

2.1 Description of the study area

On November 2000, the Chhattisgarh, India's 26th state, was created from Madhya Pradesh. It includes about one-third of the undivided Madhya Pradesh geographical area. The Chhattisgarh extends from 17^0 46'N to 240 5' N latitude and from 800 15' E to 840 20' E longitude south east of Madhya Pradesh. The state has 27 districts *viz*. Raipur, Mahasamund, Rajnandgaon, Durg, Dhamtari, Kawardha, Bilaspur, Janjgir Champa, Korba, Jashpur, Raigarh, Surguja, Koria, Kanker, Dantewada, Narayanpur, Bijapur Balrampur, Surajpur, Balodabajar, Bemetara, Balod, Gariyaband, Kondagaon, Sukuama, Mugali, Bastar (Jagdalpur). Spreading over a geographical area of 137.90 lakh hectares. The analysis was carried out with agro climatic zones of Chhattisgarh. The state has three agro climatic zones, the plains of Chhattisgarh, the plateau of Bastar and the region of Northern hills, spreading over 13.60 million hectares of geographical area of. The represented districts for agro-climatic zones and their co-ordinates as shown below.

Station	Latitude	Longitude
1.Northern hill	23°10'N	83°15'E
2. C.G. plain	21°16'N	81°36'E
3.Bastar plateau	19°08'N	82°03'E

2.2 Weather data base for analysis

Weather data for different districts of agro- climatic zones of Chhattisgarh were collected from the Department of Agrometeorology, College of Agriculture, Raipur. This study was conducted at the Department of Agrometeorology College of Agriculture Raipur provided the 23 years daily weather data for the (2000-2023)Food production data (2000-2023) i.e. Area, production & yield of different districts of Chhattisgarh state was collected from Directorate of Economics and statistic, Department of Agriculture and Farmers welfare, Ministry of farmer welfare, Govt. of India This was used for studding the effect of variation monsoon onset and withdrawal on major kharif crops. Onset and withdrawal of monsoon data in Chhattisgarh and Kerala was collected from IMD Raipur. Long term (2000-2023) rainfall data of different districts of Chhattisgarh was collected from Department of agricultural meteorology, IGKV Raipur.

2.3 Crop data for analysis

The crops during the cropping period of 2000-2023 were used to analyse the data. These data were collected from the Directorate of Economics and Statistics, Department of Agriculture and Farmers' Welfare, Ministry of Agriculture and Farmers' Welfare, Government of India.

2.4 Rainfall analysis

"Rainfall" has the meaning of the total amount of rain that falls in a particular area in a particular amount of time. Under rainfall analysis we calculate annual, seasonal rainfall and rainy days and find the relationship between monsoon onset and rainfall characteristics like rainfall amount and number of rainy days.

2.5 Statistical analysis

2.5.1 Mean $X = (\Sigma xi) / n$

2.5.2 Standard Deviation $=SD\ (\sigma) = \sqrt{\Sigma\ (X - \bar{X})\ ^2/n - 1}$

2.5.3 Variability analysis (Coefficient of variation) Standard deviation

$$CV\% = \frac{\qquad\qquad}{\qquad\qquad} X\ 100$$

3. Results and Discussion

This section explores the influence of monsoon onset timing—categorized into early, normal, and late onset—on rainfall distribution and the area under Kharif crops (rice, maize, and pigeon pea) in the Chhattisgarh plain region. The findings are based on year-wise data spanning from 2000 to 2022.

3.1 Effect of Monsoon Onset Timing on Rainfall Distribution and Kharif Crop Output in Chhattisgarh Plain zone

3.1.1 Early monsoon onset years

The early onset of monsoon occurred in 14 out of the 23 years under study. During these years, the average annual rainfall was approximately 1129 mm, with an average of 90 rainy days (Table-1). The mean area under rice cultivation was 22.89 lakh hectares, which was relatively higher compared to other onset categories. The area under pigeon pea was comparatively lower, averaging 30.65 thousand ha. Maize was the third most prominent crop during early onset years, with an average area of 16.42 thousand hectares. The correlation analysis revealed a moderate positive correlation between rainfall and rice area (r = 0.387), and between rainy days and rice area (r = - 0.481), A very weak or negative correlation between rainfall/rainy days and pigeon pea area, indicating that these crops are influenced by other factors beyond just the timing and amount of rainfall. Overall, early monsoon onset supported stable rice production, while the response of pulses remained inconsistent.

3.1.2 Normal monsoon onset years

Normal onset of monsoon was observed in 8 years. These years recorded an average rainfall of 1139 mm and around 89 rainy days. The average area under rice cultivation increased to 23.77 lakh hectares, indicating that normal onset conditions are most favourable for rice farming. Pigeon pea had an average cultivation area of 22.4 thousand ha. Maize also showed significant area coverage, averaging 13.61thousand hectares. The statistical correlation between climatic parameters and crop area during normal onset years was strongest: Rainfall and rice area showed a very strong positive correlation (r = 0.855**), Maize also had a moderate positive correlation with rainfall (r = 0.393) and rainy days (r = 0.627). These findings suggest that normal monsoon onset provides the most reliable conditions for both rice and maize, supporting consistent crop planning and output.

3.1.3 Late monsoon onset year

Late monsoon onset was recorded only in the year 2004, limiting the ability to generalize trends. However, that year received the highest annual rainfall among all (approximately 1082 mm) and 90 rainy days, which helped maintain reasonable crop coverage. Rice area was 24.05 lakh hectares, indicating resilience despite late onset. Pigeon pea area was higher than average in this year possibly due to extended monsoon rains. Due to the availability of only one year data, correlation analysis was not conducted for this category.

Table 1: Effect of Monsoon Onset Timing on Rainfall Distribution and Kharif Crop Output in Chhattisgarh plain

Early onset								
	Rice		Maize		Pigeon Pea			
Year 2000-23	**Area (Ha.)**	**Production (tonnes)**	**Area (Ha.)**	**Production (tonnes)**	**Area (Ha.)**	**Production (tonnes)**	**Total rainfall**	**Rainy days**
Average	2289318	4501139	16420.1	58549	30,656	14663	1,129	90
Rainfall correlation	0.387		0.112		-0.099			
Rainy-day correlation	0.481		-0.109		0.090			
Normal onset								
Average	2377671	5026477	13611	57115	22403	11102	1,139	89
Rainfall correlation	0.855**		0.393		-0.056			
Rainy-day correlation	0.541		0.627		0			
Late onset								
Average	2405887	3577246	14772	2000	27,634.00	14514	1,082	90
Rainy-day correlation								

3.2 Effect of Monsoon Onset Timing on Rainfall Distribution and Kharif Crop Output in Northern Hill Region

3.2.1 Early Monsoon Onset Years

During early onset years (2001, 2003, 2009, 2010, 2013, 2014, 2017-2019), the average total rainfall was about 1200 mm, and the average number of rainy days was 100 (Table-2). The average rice area was 5.612 lakh hectares, while maize covered 54.49 thousand hectares and pigeon pea had an average area of 23.07 thousand ha. Early onset resulted in generally favourable rainfall and rain day distribution. Rice area remained moderately high, but its correlation with rainfall was negative (r = -0.3791), suggesting that higher rainfall amounts did not always lead to an increase in rice area. Maize showed negligible correlation with rainfall (r = 0.0085) and a negative correlation with rainy days (r = -0.1780), indicating that maize may be adversely affected by too many rainy days. Pigeon pea showed a weak positive correlation with rainfall, suggesting some responsiveness to rainfall quantity.

3.2.2 Normal Monsoon Onset Years

Normal onset years (2000, 2002, 2004-2008, 2011-2012, 2015-2016, and 2020) showed an average rainfall of 1230 mm and 100 rainy days. The average rice area decreased slightly to 5.608 lakh hectares while maize averaged 52.90 thousand hectares. Pigeon pea area averaged 18.15 thousand ha. Despite more stable rainfall and rainy-day averages, rice showed a very weak positive correlation with rainfall (r = 0.072) and a negative correlation with rainy days (r = -0.448), implying that excess rainy days during critical stages might be detrimental. Maize and pigeon pea showed moderate to strong negative correlations with rainfall (r = -0.504 and r = -0.458, respectively), suggesting a potential vulnerability to heavy or prolonged rain.

3.2.3 Late Monsoon Onset Years

Late onset was recorded in 2021 and 2022. These years showed an average rainfall of 1,225 mm and 92 rainy days—slightly lower than other onset types. However, the average rice, Maize and pigeon pea areas were 5.688 lakh hectares, 67.93 thousand hectares and 17.90 thousand hectares, respectively, which were comparable to normal onset years. Rice and maize showed perfect negative correlation with rainfall (r = -1), which is statistically unusual and likely due to the limited number of data points (only 2 years). This indicates that in those specific years, higher rainfall was associated with lower crop areas. On the contrary, pigeon pea showed perfect positive correlations with rainfall and rainy days (r = +1), implying a strong dependency in those two years. Rainy-day correlations also followed a similar extreme pattern, reinforcing the high sensitivity of crops under delayed monsoon conditions.

Table 2: Effect of Monsoon Onset Timing on Rainfall Distribution and Kharif Crop Output in Northern hill region

Early onset								
	Rice		Maize		Pigeon Pea			
Year 2000-23	**Area (Ha.)**	**Production (tonnes)**	**Area (Ha.)**	**Production (tonnes)**	**Area (Ha.)**	**Production (tonnes)**	**Total Rainfall**	**Rainy days**
Average	561282	707823	54490	101301	23078	12616	1,200	100
Rainfall correlation	-0.379		0.008		0.087			
Rainy-day correlation	0.290		-0.178		0.162			
Normal onset								
Average	560890.5	658203	52909.67	94238	18,152	12061	1,230	100
Rainfall correlation	0.072		-0.504		-0.458			
Rainy day correlation	-0.448		-0.236		-0.133			
Late onset								
Average	560889.5	974164	67,933	184907	17,908	11382	1,225	92
Rainfall correlation	-1		-1		1			
Rainy-day correlation	-1		-0.236		1			

(-1 perfect negative correlation, 1 perfect positive correlation)

3.3.1 Early Onset of Monsoon

In the year with early monsoon onset (2012), the total rainfall recorded was 1,447 mm with 96 rainy days, providing favourable climatic conditions for sowing. The rice area was 6.377 lakh hectares and maize covered about 35.4 thousand hectares (Table-3). The area under pigeon pea was 2.14 thousand hectares. However, due to the availability of only a single data point, no statistical correlation could be calculated for this category.

3.3.2 Normal Onset of Monsoon

The years falling under normal monsoon onset (2000, 2001, 2002, 2005, 2010, 2011, 2013, 2014, 2018, 2022) showed relatively higher and stable crop outputs. The average rice area

was 6.613 lakh hectares, while maize covered about 37.02 thousand hectares. The area under pigeon pea was 2.19 thousand hectares. The average annual rainfall was 1,400 mm with approximately 95.5 rainy days.

3.3.3 Late Onset of Monsoon

Late onset years (2003, 2004, 2006, 2007, 2008, 2009, 2015-2021) showed a mixed response in crop area and rainfall distribution. The average rice area was 6.417 lakh hectares, and maize averaged 38.388 thousand hectares, slightly lower than during normal onset years. The area under pigeon pea was 1.883 thousand hectares. The average annual rainfall was 1,470 mm, with 94 rainy days.

Table 3: Effect of monsoon onset timing on rainfall distribution and kharif crop output in Bastar plateau

Early onset								
Year 2000-23	**Rice**		**Maize**		**Pigeonpea**		**Rice**	
Rice Production (tonnes)	**Area (Ha)**	**Production (tonnes)**	**Area (Hectares)**	**Production (tonnes)**	**Area (Ha.)**	**Production (tonnes)**	**Total rainfall**	**Rainy days**
2012	637782	888948	35455	63898	2141	1019	1447	96
					0.08723			
Normal onset	Normal onset	Normal onset	Normal onset	Normal onset	0.162318			
Normal onset								
Average	661318	479643	37028.3	59894	2198.1	878	1,400	95.5
Rainfall correlation	-0.709*		-0.355		-0.770*			
Rainy-day correlation	0.176		0.125		-0.609*			
Late onset								
Average	641761.7	395834	38388.92	78473	1,883	867	1,470	94
Rainfall correlation	-0.019		0.019		-0.003			
Rainy-day correlation	-0.367		-0.059		-0.285			

3.4 Effect of monsoon withdrawal timing on rainfall distribution and kharif crop output in Chhattisgarh plain

3.4.1Early Withdrawal of Monsoon

In years where the monsoon withdrawal occurred early (2000, 2002, 2004, 2005, 2006), the average rainfall was 1054 mm with an average of 85 rainy days (**Table-4**). The average rice area was recorded as 2401100 hectares, while maize and pigeon pea covered 15.35 thousand hectares and 28.30 thousand hectares, respectively.

3.4.2 Normal Withdrawal of Monsoon

During the years with normal withdrawal (2013, 2014, 2020, 2021, 2022), the average rainfall was significantly lower (1248 mm), although the rainy days remained consistent (91 days). Despite this low rainfall, the average rice area was **22.62 lakh hectares**, which is the highest among all categories. Maize and pigeon pea were grown on **2217 ha** and **22908 ha**, respectively.

3.4.3 Late Withdrawal of Monsoon

In years with delayed monsoon withdrawal (2001, 2003, 2007-2011, 2015-2019), the average rainfall was 1114 mm, and the number of rainy days remained around 90. The average rice area was **23.28 lakh hectares**, while maize covered 46.989 thousand **hectares**, and pigeon pea averaged **29.6** thousand **hectares**.

Table 4: Effect of monsoon withdrawal timing on rainfall distribution and kharif crop output in Chhattisgarh plain.

Early withdrawal								
	Rice		**Maize**		**Pigeon Pea**			
Year 2000-23	**Area (Ha.)**	**Production (tonnes)**	**Area (Ha.)**	**Production (tonnes)**	**Area (Ha.)**	**Production (tonnes)**	**Total rainfall**	**Rainy Days**
AVG	2401100	4218820	15354	34522	28,300	12210	1054	85
Rainfall correlation	0.877*		-0.790		0.553			
Rainy-day correlation	1		0.171		1			
Normal withdrawal								
Average	2262502	4128931	11648	32147	22908.4	12833	1,248	91
Rainfall correlation	0.129		0.713		0.032			
Rainy day correlation	0		0		-1			
Late withdrawal								
Average	2328155	4597886	16463	46989	29,601	12487	1,114	90
Rainfall correlation			0.356		0.398			
Rainy-day correlation	0		0		1			

(-1 perfect negative correlation, 1 perfect positive correlation)

3.5. Effect of monsoon withdrawal timing on rainfall distribution and kharif crop output in northern hill zone of Chhattisgarh

3.5.1 Early Withdrawal of Monsoon

During the early withdrawal years (2000, 2001, 2003, 2004, 2005, 2006, 2010), the average rainfall was 1,203 mm, and rainy days averaged 100 (Table-5). In this period, the average rice area was 5.60 lakh hectares, which is moderate. Maize had the highest average area of all categories at 53.05 thousand ha, possibly due to its early sowing window. Pigeon pea averaged 23.8 thousand ha.

3.5.2 Normal Withdrawal of Monsoon

Normal withdrawal years (2007, 2008, 2012, 2021) recorded an average rainfall of 1,187 mm and 96 rainy days. The average rice area increased to 1.51 lakh hectares, the highest among all categories, showing suitability under balanced rainfall. However, maize area reduced to 56.5 thousand ha, the lowest

among the categories. Pigeon pea dropped to 24.99 thousand ha.

3.5.3 Late Withdrawal of Monsoon

Late withdrawal years (2002, 2009, 2011, 2013, 2014, 2016, 2017, 2018, 2019, 2020, 2022) had the highest average rainfall (1,251 mm) and average of 99 rainy days. Rice area dropped slightly to 5.59 lakh ha, likely due to delayed harvesting issues or excess rain. Maize area further reduced to 56.98 thousand ha, showing its sensitivity to prolonged wet conditions. Pigeon pea averaged 21.8 thousand ha.

Table 5: Effect of Monsoon withdrawal Timing on Rainfall Distribution and Kharif Crop Output in Northern hill region

Early withdrawal								
	Rice		Maize		Pigeon Pea			
Year 2000-23	Area (Ha.)	Production (tonnes)	Area (Ha.)	Production (tonnes)	Area (Ha.)	Production (tonnes)	Total rainfall	Rainy days
Average	560827.6	752137	53,056.00	103630	23883	12658	1,203	100
Rainfall correlation	0.083		-0.254		0.403			
Rainy day correlation	0.083		-1		0.162			
Normal withdrawal								
Average	151031.6	733170	56511.75	112691	24995.25	11156	1,187	96
Rainfall correlation	0.475		-0.477		-0.112*			
Rainy day correlation	0		0		-0.133*			
Late withdrawal								
Average	559831.4	751716	56989.18	107029	21827	12673	1,251	99
Rainfall correlation	0.295		-0.193		0.121			
Rainy day correlation	0		0.106**		1			

(-1 perfect negative correlation, 1 perfect positive correlation)

3.6 Effect of Monsoon Withdrawal Timing on Rainfall Distribution and Kharif Crop Output in Bastar Plateau

3.6.1 Early Withdrawal Years

The years considered under early withdrawal include 2011, 2015, and 2018. During these years, the average total rainfall was 1,105 mm, with an average of 96 rainy days (Table-6). Rice area averaged 6.46 lakh hectares. Maize and pigeon pea area was 41.10 thousand hectares 1.93 thousand h.

3.6.2 Normal Withdrawal Years

Years with normal monsoon withdrawal included 2000, 2002, 2005, 2006, 2007, 2008, 2009, 2013, 2014, and 2021. The average rainfall was 1,103 mm, with an average of 95 rainy days. Rice area averaged 6.29 lakh hectares; maize area 32.6 thousand h. and pigeon pea area is 2.25 thousand ha.

3.6.3 Late Withdrawal Years

the average rice area was6.48 lakh hectares. Maize area 38.9 thousand and pigeon pea area is 4.51 thousand h.

Table 6: Effect of monsoon withdrawal timing on rainfall distribution and kharif crop output in Bastar plateau

Early withdrawal								
	Rice		Maize		Pigeon Pea			
Year 2000-23	Rice Area (Ha.)	Rice Production (tonnes)	Maize Area (Ha.)	Maize Production (tonnes)	Pigeon Pea Area (Ha.)	Pigeon Pea Production (tonnes)	Total rainfall	Rainy Days
Average	646785.7	545654	41100.67	63684	1936	969	1,105	96
Rainfall correlation	0.740		-0.996*		-0.936*			
Rainy day correlation	0		0		1			
Normal withdrawal								
Average	629376.6	704836	32663	80455	2257.6	794	1,103	95
Rainfall correlation	-0.296		-0.049		0.694*			
Rainy day correlation	0		0		0			
Late withdrawal								
Average	648849	690590	38927.2	71994	451.82	816	1939.5	186
Rainfall correlation	-0.330		0.572*		-0.087		-0.157	
Rainy-day correlation	0		0		-1		-1	

(-1 perfect negative correlation, 1 perfect positive correlation)

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