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EXTREME RAINFALL DISTRIBUTION PATTERNS IN WESTERN MAHARASHTRA INDIA: A MULTI-STATION ANALYSIS FOR CLIMATE RESILIENT AGRICULTURE

S.T. Yadav*, S.V. Bagade, S.G. Mundhe, S.K. Upadhye and P.V. Shamraj

Department of Agricultural Meteorology, College of Agriculture, Pune - 411 005, MPKV, Rahuri, Maharashtra, India.

*Corresponding author E-mail : styadav1975@gmail.com

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ABSTRACT

Rainfall variability in intensity and distribution is crucial for agricultural productivity, soil moisture balance, and water resource management across diverse agroclimatic regions. Maharashtra exhibits significant geographical diversity, from high-rainfall Western Ghat regions to low-rainfall rain-shadow areas, necessitating region-specific understanding of extreme rainfall patterns for climate-resilient agriculture. This multi-station analysis examines the variability of extreme rainfall events (≥50 mm and ≥100 mm within five consecutive days) across research stations under Mahatma Phule Krishi Vidyapeeth, Maharashtra. A total of 1762 rainfall events ≥50 mm and 872 rainfall events ≥100 mm were recorded during the study period. Meteorological data spanning 2020–2025 for Pune and 2020–2022 for other stations were analyzed to rainfall patterns. Results revealed distinct variations in extreme rainfall frequency. Western Ghat stations including Igatpuri, Lonavala, Mahabaleshwar and Kolhapur experienced frequent extreme events, with 60–75% of ≥50 mm events exceeding the ≥100 mm events. In contrast, rain-shadow region stations Solapur, Rahuri and Jalgaon recorded significantly fewer extreme events, with rainfall predominantly confined to moderate intensities. Strong inter-annual variability was observed, exemplified by Pune's sharp decline in extreme events during 2023 (only 8 rainfall events ≥50 mm and no events ≥100 mm) versus unusually high frequencies in 2024 (63 extreme events). On average, the rainfall intensity index across all stations was 49.5%, indicating that nearly half of heavy rainfall events turned into extremes. This variability in extreme rainfall patterns has direct implications for developing climate-resilient agricultural strategies. The findings support crop planning optimization, irrigation scheduling, soil erosion control measures and flood risk management across Maharashtra's diverse climatic zones. Understanding these rainfall patterns enables the development of location-specific agrometeorological advisories and water management practices, contributing to enhanced agricultural sustainability and climate adaptation strategies in the region.

Key words : Rainfall variability, Extreme rainfall events, Pune, Western Ghats, Rain-shadow zone, Climate-resilient agriculture.

Introduction

Rainfall is regarded as the most crucial climatic factor that governs crop growth, water availability and soil health in the semi-arid tropics of India. In these regions, agriculture is predominantly rainfed, making farming systems highly dependent on the timing, amount, and distribution of rainfall. Variability in rainfall not only influences crop productivity but also increases the risks of droughts, floods, and soil degradation, thereby affecting both short-term yields and long-term sustainability of agricultural resources (Rao *et al.*, 2010; Singh *et al.*, 2016). Maharashtra, with its diverse topography, experiences both high-intensity rainfall in the Western Ghats and deficit rainfall in rain-shadow regions such as Solapur and Rahuri. This variability poses challenges for sustainable agricultural production. Agrometeorological research has identified rainfall thresholds such as e”50 mm and e”100 mm extreme rainfall events as critical indicators for understanding monsoon behavior (India Meteorological Department, 2015). The occurrence, frequency, and distribution of these extreme events serve as valuable tools in crop planning, irrigation scheduling, soil and water conservation and disaster preparedness. Reliable knowledge of such patterns helps farmers and policymakers to minimize production risks, improve resource-use efficiency and enhance resilience against climate-induced stresses.

Recent studies confirm that rainfall variability and extremes are changing in Maharashtra. For example, in Western Vidarbha, long-term trends show a non-significant overall decline, but significant decreases in post-monsoon rainfall in districts such as Yavatmal (Sasane *et al.,* 2025). In north Maharashtra (Nashik, Dhule, Jalgaon, Nandurbar, Ahmednagar), the frequency of extreme rainfall events (e.g., maximum 1-day precipitation) is increasing, while dry spells are shortening (MPKV, 2024). In Marathwada, monsoonal rainfall variability has been quantified at ~24–25.5% using century-long data, indicating substantial drought risk (Pawar *et al*., 2025). Moreover, high-resolution studies over India, which include Maharashtra, show that precipitation trends are spatially heterogeneous, with some areas observing increasing rainfall while others face decline or erratic distribution (Jana *et al*., 2025). Despite the importance of rainfall variability for agricultural decision-making, systematic investigations focusing on extreme rainfall events within the jurisdiction of Mahatma Phule Krishi Vidyapeeth (MPKV) are limited. Moreover, the existing literature has primarily emphasized long-term rainfall trends, with relatively less focus on extreme rainfall thresholds (≥50 mm and ≥100 mm) that are most critical for agricultural planning. Recognizing this, the present study was undertaken to analyze the distribution and variability of extreme rainfall distribution pattern across multiple research stations in MPKV, Maharashtra. The findings are expected to contribute towards developing climate-resilient agricultural strategies.

Materials and Methods

Study Area and Data collection

Daily rainfall data for the period of 2020–2025 were collected from eleven (11) selected research stations under MPKV jurisdiction: Pune, Igatpuri, Lonavala, Mahabaleshwar, Solapur, Rahuri, Dhule, Pimpalgaon Basavant, Kolhapur, Kasbe Digraj, and Jalgaon. Rainfall events were categorized into two thresholds for extreme rainfall: ≥50 mm and ≥100 mm within 24 hours. These thresholds were used to identify and quantify extreme rainfall events (EREs) across stations.

Classification of Rainfall events

Rainfall events were categorized into ≥50 mm and ≥100 mm within 24 hours. This classification facilitated the quantification of both the frequency and intensity of rainfall events during the study period.

Trend analysis

Year-wise variability in rainfall events was analyzed for the period 2020–2025 to evaluate trends in rainfall. This analysis focused on identifying fluctuations in the number and magnitude of rainfall events across years. Particular attention was given to the frequency of extreme rainfall events, which were compared across all observation stations. This enabled the assessment of inter-annual variability and the detection of patterns or anomalies in rainfall occurrence.

Rainfall Intensity Index

The Rainfall Intensity Index was calculated for each station as the ratio of Extreme Rainfall Events e”50 mm and e”100 mm within 24 hours. This index provided a quantitative measure of the relative intensity of rainfall events, allowing comparison of rainfall severity between different stations and years.

$$RII = \frac{\text{Total Number of rainfall events} \geq 100\text{ mm}}{\text{Total Number of rainfall events} \geq 50\text{ mm}} \times 100$$

Where,

RII = Rainfall Intensity Index

Data analysis tools

All statistical analyses were performed using MS Excel, and tabular representations were generated to visualize trends in rainfall frequency and intensity.

Results and Discussion

Frequency of Rainfall Events at Pune Station (2020–2025)

Rainfall variability, particularly the occurrence of extreme rainfall events, plays a crucial role in agricultural planning, water resource management and disaster preparedness. To assess recent rainfall trends, the frequency of rainfall events at Pune station during the period 2020–2025 was analyzed (Table 1).

The analysis revealed that Pune station recorded 200 rainfall events of ≥50 mm during 2020–2025, of which 51 events were rainfall events ≥100 mm. Year-wise variation is evident at Pune, where the number of extreme rainfall events fluctuated considerably, the highest frequency of ≥50 mm was observed in 2022 (49 events) followed closely by 2024 (48 events), indicating years of highly concentrated rainfall activity. Similar inter-annual variability was observed at other stations, reflecting the

Table 1 : Frequency of extreme (≥50 mm) and (≥100 mm) Rainfall Events at Pune Station (2020–2025).

Year	Rainfall Events (≥50 mm)	Rainfall Events (≥100 mm)
2020	45	10
2021	24	5
2022	49	11
2023	8	0
2024	48	15
2025	26	10
Total	**200**	**51**

Table 2 : Frequency of Rainfall events at High Rainfall (Western Ghat) Stations.

Station	Year	Rainfall events (≥50 mm)	Rainfall events (≥100 mm)
Igatpuri	2020	94	57
	2021	112	52
	2022	98	80
Total		**304**	**189**
Lonavala	2020	92	62
	2021	107	84
	2022	86	70
Total		**285**	**216**
Mahabaleshwar	2020	96	71
	2021	119	86
	2022	88	64
Total		**303**	**221**
Kolhapur	2020	40	25
	2021	48	13
	2022	53	28
Total		**141**	**66**

strong influence of monsoon dynamics and possibly large-scale climate drivers such as ENSO and IOD (Rajeevan *et al.*, 2006; Raje and Mujumdar, 2010).

In contrast, 2023 recorded the lowest number of rainfall events (8 events), with no rainfall events ≥100 mm, suggesting a markedly dry monsoon year. The frequency of extreme rainfall events (≥100 mm) was highest in 2024 (15 events), highlighting an increasing tendency towards short-duration, high-intensity rainfall. This variability demonstrates the uncertainty of monsoon rainfall, consistent with climate change projections for semi-arid India (Roxy *et al.*, 2017). From an agricultural perspective, 2023 conditions could lead to delayed sowing, low yields, and increased drought stress, whereas 2024 conditions may result in waterlogging, soil erosion, and pest outbreaks.

Overall, the period under study reflects considerable inter-annual variability in rainfall distribution. While 2020, 2022 and 2024 witnessed frequent and intense rainfall events, 2021 and 2023 were comparatively deficient. This variability underscores the growing uncertainty in rainfall patterns, possibly linked to changing climate dynamics.

Frequency of Rainfall Events at High Rainfall (Western Ghat) Stations

The Western Ghats region of Maharashtra is characterized by orographic rainfall, making it one of the highest rainfall zones in India. The frequency of ≥50 mm and ≥100 mm events was analyzed at four key stations Igatpuri, Lonavala, Mahabaleshwar, and Kolhapur during the years 2020 to 2022 (Table 2).

Stations in the Western Ghats belt recorded the highest concentration of extreme rainfall. It showed sharp contrasts between Ghat and rain-shadow stations. Igatpuri (304 ≥50 mm, 189 ≥100 mm), Lonavala (285 ≥50 mm, 216 ≥100 mm), and Mahabaleshwar (303 ≥50 mm, 221 ≥100 mm) experienced exceptionally high frequencies of intense rainfall, underscoring the influence of orographic lifting and sustained monsoon activity in these regions (Deshpande *et al.*, 2016). Similarly, Kolhapur (66 events) also showed a relatively high incidence of extreme rainfall. These findings are consistent with the observed tendency of the Western Ghats to receive frequent short-duration, high-intensity spells (Prasad and Singh, 2019).

The analysis shows that the Western Ghat stations recorded extremely high frequencies of extreme rainfall events, with considerable inter-annual variation.

- Igatpuri recorded a total of 304 rainfall events ≥50 mm and 189 ≥100 mm during 2020–2022. The highest number of extreme events occurred in 2022 (80 events).
- Lonavala experienced 285 rainfall events ≥50 mm and the highest extreme rainfall frequency 216 events rainfall events ≥100 mm among the stations studied, highlighting its vulnerability to intense precipitation.
- Mahabaleshwar, a well-known hill station, recorded 303 rainfall events ≥50 mm and 221 rainfall events ≥100 mm, with 2021 being the wettest year (205 extreme events).
- Kolhapur, located on the leeward side compared to the other stations, had comparatively fewer events, with 141 rainfall events ≥50 mm and 66

Table 3 : Frequency of Rainfall events at Rain-Shadow and Semi-Arid Stations.

Station	Year	Rainfall events (≥50 mm)	Rainfall events (≥100 mm)
Solapur	2020	16	5
	2021	15	1
	2022	44	2
Total		**75**	**8**
Rahuri	2020	54	10
	2021	35	5
	2022	42	10
Total		**131**	**25**
Dhule	2020	24	12
	2021	21	8
	2022	17	4
Total		**62**	**24**
Jalgaon	2020	29	11
	2021	33	5
	2022	37	7
Total		**99**	**23**

Table 4 : Overall Summary of Rainfall events at All Stations.

Category	Rainfall events (≥50 mm)	Rainfall events (≥100 mm)
All Stations total	1762	872

≥100 mm. However, it still recorded consistent high-intensity rainfall, particularly in 2022.

Comparative Insights

Among the four stations, Mahabaleshwar and Lonavala showed the highest frequency of extreme rainfall events, exceeding 200 events over three years. Igatpuri also experienced frequent heavy rainfall, while Kolhapur recorded relatively lower frequencies due to its geographic location further inland.

The data indicate a tendency toward short-duration, high-intensity rainfall episodes, particularly in 2021 and 2022, which may increase risks of flash floods, landslides, and soil erosion in the Western Ghats region.

Frequency of Rainfall Events at Rain-Shadow and Semi-Arid Stations

Rain-shadow and semi-arid regions of Maharashtra, such as Solapur, Rahuri, Dhule, and Jalgaon, typically experience limited rainfall compared to the Western Ghats. However, short-duration heavy and extreme rainfall events also occur in these regions, significantly impacting agriculture. To understand recent rainfall trends, the frequency of rainfall ≥50 mm and ≥100 mm events was analyzed for the years 2020–2022 (Table 3). In rain-shadow and semi-arid stations such as Solapur (75 ≥50 mm, 8 ≥100 mm) and Jalgaon (99 ≥50 mm, 23 ≥100 mm) showed much lower rainfall event frequencies, despite recording a moderate number of heavy rainfall days. This highlights the climatic variability within short spatial gradients across Maharashtra (Guhathakurta *et al.*, 2011).

The difference between ghta and rain shadow region can be attributed to the orographic effect of the Western Ghats, enhancing rainfall on windward slopes while creating dry conditions on leeward sides.

The analysis indicates that even in rain-shadow and semi-arid zones, significant heavy rainfall events were observed during the study period:

- Solapur recorded the lowest number of events with 75 heavy rainfall and 8 extreme events in three years. The year 2022 stood out with an unusually high 44 heavy rainfall events, although extreme events remained low (2).
- Rahuri had the highest frequency among these stations, with 131 heavy rainfall events and 25 extreme events, indicating substantial inter-annual rainfall variability.
- Dhule recorded 62 heavy rainfall events, but a relatively high proportion were extreme events (24), showing the occurrence of sudden, high-intensity showers.
- Jalgaon experienced 99 heavy rainfall events and 23 extreme rainfall events, with consistent occurrences across all three years.

Comparative insights

While the absolute numbers are lower compared to the Western Ghat stations, the relative frequency of extreme events is notable. Dhule and Jalgaon, in particular, show that a significant share of heavy rainfall events exceeded 100 mm, despite being in semi-arid settings. This indicates a shift towards erratic and intense rainfall patterns, which could lead to flash floods, soil erosion, and crop losses in otherwise drought-prone regions.

Overall Summary of Rainfall events at all Stations

The frequency of extreme (≥50 mm) and (≥100 mm) rainfall events across 11 research stations under MPKV during 2020–2025 shows distinct variability. The analysis of rainfall data from Western Ghat (high rainfall), rain-shadow, semi-arid, and inland stations of Maharashtra during recent years provides a comprehensive picture of extreme rainfall occurrences. Table 4 summarizes the cumulative frequency of rainfall events ≥50 mm and ≥100 mm across all stations studied.

The compiled data revealed that across all research stations, a total of 1762 rainfall events ≥50 mm were recorded, of which 872 events ≥100 mm were extreme rainfall episodes. This means that nearly 49.5% of heavy rainfall events exceeded the 100 mm threshold, highlighting a strong tendency toward short-duration, high-intensity rainfall. Similar increases in the frequency of extreme rainfall over India have been reported in earlier studies (Goswami *et al.*, 2006; Roxy *et al.*, 2017).

Overall, the results indicate that while the Ghats region is highly vulnerable to frequent and intense rainfall, leading to increased risks of floods, the semi-arid stations face contrasting challenges of rainfall variability that may affect agriculture and water resources (Table 5). These findings emphasize the importance of climate-resilient planning, disaster preparedness, and adaptive agricultural strategies in Maharashtra.

This high frequency of extreme events has several important implications:

- Western Ghat stations such as Mahabaleshwar, Lonavala, and Igatpuri contributed substantially to the total, reflecting the impact of orographic lifting.
- Rain-shadow and semi-arid stations (e.g., Rahuri, Jalgaon, Dhule) also recorded a considerable number of extreme events, despite being located in lower rainfall zones.
- The distribution shows a growing risk of hydrological extremes such as flash floods, waterlogging, landslides in hilly terrain, and soil erosion in agricultural areas.

Proportion of extreme rainfall events and rainfall intensity index across stations

The Rainfall Intensity Index (Table 6) indicated that 60–70% of heavy rainfall events at Ghat stations escalated to extreme rainfall events, reflecting very high rainfall intensity. Such conditions often result in soil erosion, flash floods, and crop damage. In contrast, semi-arid stations such as Solapur, Rahuri and Jalgaon had intensity ratios below 25–30%, suggesting lower intensity rainfall but higher vulnerability to water scarcity. Agrometeorologically, these findings stress the need for soil conservation in Ghat zones and rainwater harvesting in rain-shadow.

Table 5 : Frequency of Extreme (≥50 mm) and (≥100 mm) Rainfall events at MPKV Research Stations (2020–2025).

Station name	Year	Rainfall events (≥50 mm)	Rainfall events (≥100 mm)
Pune	2020	45	10
	2021	24	5
	2022	49	11
	2023	8	0
	2024	48	15
	2025	26	10
Total		200	51
Igatpuri	2020	94	57
	2021	112	52
	2022	98	80
Total		304	189
Lonavala	2020	92	62
	2021	107	84
	2022	86	70
Total		285	216
Mahabaleshwar	2020	96	71
	2021	119	86
	2022	88	64
Total		303	221
Solapur	2020	16	5
	2021	15	1
	2022	44	2
Total		75	8
Rahuri	2020	54	10
	2021	35	5
	2022	42	10
Total		131	25
Dhule	2020	24	12
	2021	21	8
	2022	17	4
Total		62	24
Pimpalgaon Basavant	2020	26	1
	2021	23	8
	2022	51	17

Table 5 continued...

Table 5 continued...

Total		100	26
Kolhapur	2020	40	25
	2021	48	13
	2022	53	28
Total		141	66
Kasbe Digraj	2020	23	10
	2021	18	12
	2022	21	1
Total		62	23
Jalgaon	2020	29	11
	2021	33	5
	2022	37	7
Total		99	23
All Stations total		1762	872

Rainfall intensity, expressed as the proportion of extreme events (≥50 mm) and (≥100 mm), is a critical indicator of monsoon behavior and its impact on agriculture and water resources. In Maharashtra, the intensity index varies widely across stations, reflecting the state's diverse topography. Lonavala (75.8%), Mahabaleshwar (72.9%), and Igatpuri (62.2%) showed very high intensity values, indicating that most heavy rainfall events in these Western Ghats stations escalate into extremes. Such conditions often result in runoff, soil erosion, and flood hazards.

By contrast, semi-arid rain-shadow areas such as Solapur (10.7%) and Rahuri (19.1%) recorded low rainfall intensity, highlighting scarcity of extreme events and greater drought vulnerability. Intermediate stations like Kolhapur (46.8%) and Dhule (38.7%) showed moderate intensity, balancing flood and drought risks. On average, nearly 50% of heavy rainfall events across all stations turned into extreme events, demonstrating the dual challenge of water excess and water deficit within the same state. These findings underline the importance of station-specific adaptation measures in crop planning, soil and water conservation, and disaster preparedness. On average, the rainfall intensity index across all stations was 49.5%, indicating that nearly half of extreme rainfall events turned into extremes.

Rainfall Intensity Index across Stations

The Rainfall Intensity Index indicated that 60–70% of rainfall events ≥50 mm at Ghat stations escalated to rainfall events ≥100 mm, reflecting very high rainfall intensity. Such conditions often result in soil erosion, flash floods and crop damage. In contrast, semi-arid stations such as Solapur, Rahuri, and Jalgaon had intensity ratios below 25–30%, suggesting lower intensity rainfall but higher vulnerability to water scarcity. Agrometeorologically, these findings stress the need for soil conservation in Ghat zones and rainwater harvesting in rain-shadow zones.

Agrometeorological implications

The combined results underscore major challenges for farmers:

- **Crop Planning:** Short-duration, drought-tolerant crops in dry zones; flood-tolerant and erosion-resistant crops in wet zones.
- **Water Management:** Drainage and bunding in Ghat stations; micro-irrigation and farm ponds in semi-arid stations.
- **Soil Conservation:** Contour bunding, cover crops,

Table 6 : Proportion of extreme rainfall events and rainfall intensity index across stations.

S. no.	Station name	Total rainfall events ≥50 mm	Total rainfall events ≥100 mm	Rainfall Intensity Index (%)
1.	Pune	200	51	25.5
2.	Igatpuri	304	189	62.2
3.	Lonavala	285	216	75.8
4.	Mahabaleshwar	303	221	72.9
5.	Solapur	75	8	10.7
6.	Rahuri	131	25	19.1
7.	Dhule	62	24	38.7
8.	Pimpalgaon Basavant	100	26	26.0
9.	Kolhapur	141	66	46.8
10.	Kasbe Digraj	62	23	37.1
11.	Jalgaon	99	23	23.2
	All Stations	**1762**	**872**	**49.5**

and vegetative barriers in high-rainfall zones to reduce erosion.

- **Climate Risk Management:** Weather advisories, crop insurance, and contingency crop planning are critical for resilience.

Conclusion

The study indicates that Pune has experienced increasing intensity and variability of rainfall events in recent years, with significant implications for agriculture planning. The Western Ghat stations exhibited a very high frequency of extreme rainfall events emerging as the most affected locations. The study highlights that rain-shadow and semi-arid stations of Maharashtra are increasingly experiencing extreme rainfall events, though their overall rainfall is less compared to high-rainfall zones. The occurrence of multiple extreme rainfall events in certain years highlights the need for improved weather forecasting, adaptive water management strategies, and Climate-resilient agricultural practices to mitigate the adverse impacts of such climatic fluctuations.

References

Deshpande, N.R., Kulkarni B.D. and Kumar P. (2016). Characteristics of hourly rainfall over the Western Ghats region of India. *Theoretical and Applied Climatology,* **123(3–4)**, 621–635. https://doi.org/10.1007/s00704-015-1385-7

Goswami, B.N., Venugopal V., Sengupta D., Madhusoodanan M.S. and Xavier P.K. (2006). Increasing trend of extreme rain events over India in a warming environment. *Science,* **314(5804)**, 1442–1445. https://doi.org/10.1126/science.1132027

Guhathakurta, P., Sreejith O.P. and Menon P.A. (2011). Impact of climate change on extreme rainfall events and flood risk in India. *J. Earth System Sci.*, **120(3)**, 359–373. https://doi.org/10.1007/s12040-011-0082-5

India Meteorological Department (IMD) (2015). *Southwest Monsoon Rainfall: Characteristics, Variability and Trends*. Ministry of Earth Sciences, Government of India.

Jana, S., Ghosh S. and Ghosh R. (2025). Developing high-resolution data to assess spatiotemporal patterns of temperature and precipitation trends and drought severity over India. *Scientific Reports*, **15**, 13889. https://doi.org/10.1038/s41598-025-13889-1

Maiti, S., Dutta M. and Bandyopadhyay A. (2024). Optimal rainfall threshold for monsoon rice production in India. *Commun. Earth Environ.*, **5(1)**, 1414. https://doi.org/10.1038/s43247-024-01414-7

MPKV (2024). Trends of temperature and precipitation extreme indices in north Maharashtra. *ResearchGate preprint*. https://www.researchgate.net/publication/386328063

Pawar, N., Kadam A. and Kulkarni S. (2025). Assessment of meteorological drought risk in Marathwada region, Maharashtra. *Pure and Applied Geophysics*. https://doi.org/10.1007/s00024-025-03728-9.

Prasad, K. and Singh O. (2019). Trends in extreme rainfall events over Maharashtra, India. *Mausam*, **70(3)**, 475–484. https://doi.org/10.54302/mausam.v70i3.384

Raje, D. and Mujumdar P.P. (2010). Constraining uncertainty in regional hydrologic impacts of climate change: Nonstationarity in downscaling. *Water Resources Research*, **46(7)**. https://doi.org/10.1029/2009WR008425

Rajeevan, M., Bhate J., Kale J.D. and Lal B. (2006). High resolution daily gridded rainfall data for the Indian region: Analysis of break and active monsoon spells. *Curr. Sci.*, **91(3)**, 296–306.

Rao, K.V., Raju B.M.K., Rao C.A.R., Reddy K.S., Osman M. and Rao V.U.M. (2010). Climatic variability and crop production in semi-arid tropics of India. *Indian J. Agricult. Sci*., **80(7)**, 561–568.

Rao, K.N., Reddy D.R. and Raju B.M. (2010). Rainfall variability and its impact on crop production in semi-arid tropics. *J. Agrometeorol*., **12(2)**, 159–166.

Roxy, M.K., Ghosh S., Pathak A., Athulya R., Mujumdar M., Murtugudde R. and Rajeevan M. (2017). A threefold rise in widespread extreme rain events over central India. *Nature Communications,* **8**, 708. https://doi.org/10.1038/s41467-017-00744-9

Singh, D., Tsiang M., Rajaratnam B. and Diffenbaugh N.S. (2016). Observed changes in extreme wet and dry spells during the South Asian summer monsoon season. *Nature Climate Change*, **4**, 456–461.

Sasane, S., Deshmukh P. and Wagh V. (2025). Assessment of rainfall variability in the Western Vidarbha region of Maharashtra, India. *ResearchGate preprint*. https://www.researchgate.net/publication/394297966

Singh, R., Wani S.P., Pathak P. and Sahrawat K.L. (2016). Climate variability and agriculture: Impact on water availability, crop productivity and soil health in semi-arid tropics of India. *Curr. Sci.*, **110(7)**, 1255–1260.