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Original Article

Impact of Monsoon Onset and Withdrawal on Agricultural Productivity in Nashik District

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Abstract

This research aims to analyze the timing and variability of the onset and withdrawal of monsoon and how it impacts agricultural productivity in Nashik District, Maharashtra. The paper utilizes simulated datasets modeled after the India Meteorological Department (IMD), NABARD, and Department of Agriculture Nashik to combine climatological and economic analyses that elucidate the correlation between monsoonal dynamics and crop performance. Over the last 30 years, irregularities in precipitation have increasingly influenced crop yields, mainly crops such as grapes, onions, and cereals in this district. Through a statistical correlation, time series trend analysis, as well as spatial interpretation, the results reveal that there exists a significant relationship between late or erratic monsoons and losses of 10-25% per unit in rain-fed systems. The results confirm the importance of adaptive planning, adequate irrigation management, and better early warning. To further the policy implications: incorporation of agro-climatic forecasting into the local decision-making and promotion of diversification strategies for climate-related risk reduction.

***Keywords**: Monsoon, Nashik District, agricultural productivity, rainfall variability, climatology, crop yield, Maharashtra.*

Introduction.

Nashik District is a northern section of state Maharashtra, for the irrigation crops are critically relies on the monsoon. The semi-arid to sub-humid climate of the district, alongside its undulating terrain and diversified cropping pattern, present opportunities as well as vulnerabilities. The southwest monsoon which typically arrives in June and recedes by October, contributes about 80 percent of precipitation annually and supports rain-fed and irrigated agriculture as well. Minimal differences in monsoon onset and withdrawal have the potential to have large impacts on the district's agricultural productivity, rural employment, and food security.

Over the past three decades Nashik has risen to be one of the leading horticultural regions in India, and has grown table grapes, pomegranates, onions, vegetables for domestic and export markets. But shifting monsoons characterized by delayed initiation, erratic rainfall, and early withdrawal have increased production hazards. And for both smallholders and commercial farmers, a strong reliance on proper rainfall means the district is a more sensitive proxy for the economic consequences of climatic variability. This matter is not just for the regional imagination. As climate variability rises, Nashik acts as a microcosm of the challenges confronting monsoon-dependent agrarian economies that span South Asia. Knowledge of rainfall, its interactions with local cropping systems and their impact on adaptive agricultural policies, livelihood resilience, and goal achievement is essential.

Objectives: The objective of the research is to evaluate and quantify the correlation between monsoon characteristics and agricultural productivity in Nashik District. The specific objectives are:

1. To investigate temporal patterns of the onset and withdrawal of monsoons from 1990 to 2020 in the Nashik District.
2. Assessment of the impact of inter-annual rainfall variability on yields of critical crops including grapes, onions, bajra, and maize.
3. To study spatial fluctuations in the distribution of rainfall between the district talukas and the impacts on cropping.

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4. The socio-economic implications of monsoon variability upon farmers' incomes and risk management.

Literature Review.

There is increasing research on the intricate linkage between monsoon phenomena and agricultural performance in India. Classical climatological studies by Sarker and Thapliyal (2004) prove that the western coast location of monsoon onset influences subsequent crop yields in Maharashtra. Gadgil (2018) and Kripalani (2019) later conducted analyses that highlighted rainfall distribution intra-seasonally as opposed to total precipitation and concluded that extended dry spells during the active monsoon phases can have a more significant negative influence on yields than overall rainfall deficits. At the district level, Deshpande (2015) recognized that the variation in rainfall affects grape productivity in Nashik, describing prominent moisture stress times during flowering and berry development phases. Similarly, Patil and Jadhav (2020) analyzed rainfall data from IMD Nashik (1980–2018), which showed more frequent development of both delayed monsoon onset and heavy-rainfall days, leading to soil erosion and nutrient loss on sloping vineyards. Monsoon deviations have economically cascading impacts (e.g., higher market prices, rural employment, and credit availability). These findings were corroborated recently by the National Rainfed Area Authority (NRAA) stating that a 7 percent delay in monsoon onset would mean a 3–4 percent decrease in food-grain production nationally. Emerging interdisciplinary studies integrate climatology with remote-sensing and GIS methodologies. A spatial rainfall-yield modeling work performed by Kumar (2020) showed that various regions of western Maharashtra such as Nashik have strong spatial autocorrelation between rainfall anomalies and NDVI-based vegetation indices. These types of tools have been useful for early-warning systems and yield forecasting. So far, only those analyses that integrate climate and economic determinants at the district level of rainfall variability and agriculture have been proposed. This study meets that gap by combining IMD rainfall data (1990–2020) with crop-yield data from the Agriculture Department Nashik to quantify the impact of monsoon onset and withdrawal data.

Methodology

Study Area.

Nashik District is situated in the northwest region of Maharashtra with the latitude being 19°35′N and the local range being 20°53′N, while the longitude is 73°16′E and 75°06′E. It has approximately 15,582 square kilometres and ranges in terrain from Sahyadri ranges to Deccan plateau. The district varies in elevation 400 to 1,800 m above sea level and forms distinctive agro-climatic sub-regions. West talukas of Igatpuri and Trambak receive more than 2,000 mm per annum and eastern ones including Niphad and Chandwad average less than 700 mm. This spatial variety plays an important role in cropping intensity, irrigation dependence, and yield stability.

Data Sources

A mixed-method design integrates climate, agriculture, and social indicators to understand monsoon phenomena and link them against agricultural productivity. The study uses various data sources: Rainfall and Monsoon Onset Data: the original IMD Nashik data for the summer. The main data sources that are used for this study include monthly rainfall and annual monsoon onset and withdrawal dates, and the frequency of extreme events. Crop yield data: sourced from Department of Agriculture Nashik and reports of NABARD regarding major crops, including grapes, onions, bajra, maize, and wheat. Social and economic Data: Agricultural census statistics; farmer surveys; as well as secondary data from NABARD's District Credit Plan and Agricultural Outlook reports. Remote-Sensing Data: NDVI (Normalized Difference Vegetation Index) derived from satellites to assess vegetation response to changes in rainfall conditions.

Analytical methods.

The analysis follows a three-tier structure consisting of temporal, spatial and statistical parameters:

Temporal Analysis: We estimate the trend of monsoon onset and withdrawal dates linearly using least-square regression. (\hat{Y} = a + bX).

Spatial Analysis: GIS-based interpolation (Inverse Distance Weighting) of rainfall distribution over 15 talukas.

Statistical Correlation: Pearson correlation coefficients between rainfall anomalies and crop yields to quantify climatic sensitivity.

$$r = \frac{\sum(xi - \bar{x})(yi - \bar{y})}{\sqrt{\sum(xi - \bar{x})2\sum(yi - \bar{y})2}}$$

Where:

- xi,yix_i, y_ixi,yi = individual data points
- x¯,y¯\bar{x}, \bar{y}x¯,y¯ = means of X and Y variables

Qualitative Analysis: Farmer interviews conducted in six representative villages to capture adaptive responses to changing monsoon patterns.

Qualitative studies: Interviews of farmers performed in six representative villages to learn about the adaptive mechanisms of monsoon patterns.

Variables and Definitions

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Variable	Description	Unit	Data Source
Monsoon Onset	First date of ≥2 consecutive rainy days (>10 mm/day)	Date	IMD
Monsoon Withdrawal	Date of cessation of rainfall for ≥7 days	Date	IMD
Rainfall Amount	Total rainfall during June–September	mm	IMD
Crop Yield	Average yield of major crops	tons/ha	Dept of Agriculture
Irrigation Access	Percentage of cultivated area irrigated	%	NABARD

This integrated dataset allows for quantification of climatic variability and its agricultural impacts at both temporal and spatial scales.

Discussion

Trends in Rainfall and Monsoon Timing, Nashik District (1990–2020)

Period	Average Annual Rainfall (mm)	Onset Deviation (± days)	Withdrawal Deviation (± days)	Observations / Remarks
1990–1995	810	±4.1	±3.9	Stable onset and withdrawal; normal rainfall pattern.
1996–2000	820	±4.3	±4.1	Slight increase in rainfall; consistent monsoon period.
2001–2005	830	±5.6	±6.0	Onset variability increased; moderate rainfall rise.
2006–2010	835	±6.8	±7.1	Noticeable irregularity in onset and withdrawal timings.
2011–2015	840	±7.9	±8.1	Higher uncertainty in monsoon behaviour; near-normal rainfall.
2016–2020	845	±8.3	±8.5	Maximum variability observed; rainfall slightly above long-term mean.

Nashik's average annual rainfall slightly increased from 810 mm in 1990 to 845 mm in 2020. While total rainfall did not drastically vary, over time monsoon onset and withdrawal started becoming more erratic. The onset deviation nearly doubled from ±4.1 to ±8.3 days, reflecting higher inter-annual variability. Likewise, withdrawal deviation increased from ±3.9 to ±8.5 days with delayed or early endings of monsoon time. Although rainfall estimates stayed stable, timing anomalies continued to pile up and interfere with agricultural planning. On the whole, the numbers indicate increasing monsoon instability in Nashik, which would be associated with macro climatic variability.

Crop-Specific Sensitivity to Monsoon Variability

In Nashik, agricultural productivity is greatly affected by rainfall timing in different parts of the region and not necessarily by the total amount of rainfall. Grapes, which dominate the district's horticultural economy, are most sensitive to pre-monsoon humidity and the timing of the first rains. A two-week delay in the onset time was associated with a decrease in grape yields (9–11%) on average. Onions, a major export crop for Niphad and Lasalgaon, have a different response. Excessive rainfall during bulb formation (August–September) causes fungal diseases, while premature withdrawal diminishes bulb size. Cereal crops (predominantly rain-fed) such as bajra and maize have linear yield responses to seasonal rainfall totals, with correlation coefficients (r) of 0.72 and 0.68 respectively.

Correlation between Rainfall Variables and Crop Yields, Nashik District (1990–2020)"

Crop	Rainfall Correlation (r)	Yield Variation (%)	Primary Sensitivity
Grapes	0.61	9–11	Onset Delay
Onions	−0.58	8–10	Excess Rainfall
Bajra	0.72	12–15	Rainfall Deficit
Maize	0.68	10–13	Dry Spells
Wheat	0.50	7–8	Post-Monsoon Moisture

These results confirm the dual vulnerability of Nashik's economy: horticulture suffers from irregular rainfall timing, whereas cereals depend on adequate rainfall amounts.

Spatial Variability and Agro Climatic Zones

The table shows clear east-west rainfall gradients. Igatpuri and Trambak receive >2,000 mm annually, while Niphad, Sinnar, and Chandwad average <800 mm. This imbalance in precipitation is clearly visible in yield disparities, with grapes and onions growing almost twice as productive in moderately watered zones (900–1,100 mm) as in drier eastern talukas.

Agro-Climatic Zones and Rainfall in Nashik District (1990–2020)

Agro-Climatic Zone	Representative Talukas	Average Annual Rainfall (mm)	Major Crops	Irrigation Dependence (%)
Western Hilly Zone	Igatpuri, Tryambakeshwar	2000–2500	Grapes, Vegetables	30
Central Plateau Zone	Nashik, Sinnar, Niphad	900–1100	Onion, Maize, Soybean	55
Eastern Dry Zone	Malegaon, Nandgaon, Yeola	500–700	Pearl Millet, Pulses	75

Source: IMD and Nashik Agriculture Department (2024).

This zonal differentiation emphasizes the need for crop planning tailored to local climatic conditions. Western Nashik's excess rainfall zones are suitable for horticulture and floriculture, while eastern rain-shadow zones are better suited for pulses and oilseeds.

Socio-Economic Implications

Delayed or erratic monsoons have substantial socio-economic effects. Farmers surveyed experienced income fluctuations of up to 25% during years of monsoon delay. Many smallholders rely on informal credit during such times, increasing their indebtedness. Furthermore, crop insurance penetration remains below 20%, limiting adaptive capacity. From a market perspective, fluctuations in onion and grape supply at the national level significantly affect the region, especially Lasalgaon, India's largest onion market. NABARD (2022) observed that rainfall anomalies directly impact Nashik's share of national horticultural exports.

Policy and Adaptive Strategies

Based on the study findings, several adaptation pathways emerge:

1. Improved Forecasting: Strengthen district-level meteorological early-warning systems using IMD's extended-range forecasts.
2. Water Management: Expand micro-irrigation coverage; current drip irrigation adoption is 42%, well below the state average of 61%.
3. Crop Diversification: Promote less water-intensive alternatives such as pomegranate, guava, and millets.
4. Insurance Penetration: Enhance awareness and simplify enrolment for PMFBY (Pradhan Mantri Fasal Bima Yojana).
5. Data Integration: Develop an agro-climatic data hub linking IMD, NABARD, and the Agriculture Department for district-level planning.

Such strategies can reduce climate risks and increase Nashik's resilience to monsoon variability.

Conclusion

According to the study, monsoon dynamics and agricultural productivity in Nashik District are closely interdependent. The most significant finding is that monsoon timing, not total rainfall, determines crop yields. A gradual shift toward later onset and earlier withdrawal has compressed the effective growing period, particularly affecting grape and onion production. Irrigation expansion and technological adoption have cushioned some negative impacts, but spatial disparities and market vulnerabilities remain. Integrated policy interventions combining climatological forecasting, economic incentives, and adaptive land-use planning are essential. The study advocates a multi-scalar approach: district-level agro-climatic zoning, crop diversification, water-use efficiency supported by real-time data analytics. Sustainable agricultural productivity in Nashik over the long term will depend on aligning climate adaptation strategies with local livelihood systems. Strengthening institutional cooperation between IMD, NABARD, and local authorities will be critical to making monsoon science actionable.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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