

Rainfall Variability and Agricultural Productivity: A Case Study in Cooch Behar District of West Bengal, India

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Abstract

In India's monsoon-dependent regions, variability in rainfall has emerged as an important climatic factor which heavily impact agricultural productivity. This study examines how agricultural productivity and seasonal rainfall variability relate to each other in West Bengal's Cooch Behar district, which is primarily an agrarian area in the sub-Himalayan plains. Based on secondary data which has been collected through official agricultural and meteorological sources, the study uses a descriptive and trend-based analytical methodology. The pre-monsoon, monsoon and post-monsoon are used to group rainfall data in order to analyze how they affect important crops like vegetables, paddy, jute, wheat, mustard, and maize. According to the results, crop productivity is highly affected by irregular rainfall distribution, delayed monsoon onset, intense rainfall, and dry spells, even though the district receives a comparatively high amount of rainfall annually. Paddy is found to be the most rainfall-sensitive crop, while other crops exhibit varying degrees of vulnerability depending on seasonal requirements and growth stages. Both excess and deficient rainfall contributes to production instability, increased cultivation costs, and income uncertainty for farmers. The study highlights the need for improved irrigation infrastructure, climate-resilient crop varieties, crop diversification, and strengthened flood management systems to ensure sustainable agricultural development in the district.

Keywords: Rainfall Variability, Agricultural Productivity, Seasonal Rainfall, Monsoon Dependence, Crop Sensitivity, Climate Risk; Agricultural Sustainability.

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INTRODUCTION

India is a country where agricultural activities are largely dependent on rainfall, particularly in regions that rely predominantly on natural precipitation. In the agricultural sector sowing of seeds, transplantation of seedlings, and harvesting of crops are significantly influenced by the Indian monsoon system. A district like Cooch Behar which is located in the northern region of West Bengal depends heavily on agriculture; especially the rural population of the district relies on agriculture for their living. During the southwest monsoon season, the district receives a lot of rainfall, which helps to grow important crops including vegetables, paddy, jute, and maize. Seasonal rainfall not only affects soil moisture availability but also affects cropping intensity, input use, and overall farm income. A timely and evenly distributed monsoon ensures consistent agricultural productivity but unpredictable rainfall patterns can upset the agricultural calendar and negatively impact farmers' incomes.

During a certain period, the changes in the amount of, timing, duration and distribution of rainfall is known as rainfall variability. On the other hand, when the monsoon season is unpredictable due to its late arrival, inconsistent regional distribution, prolonged dry spells, and brief burst of intense rainfall is the example of unpredictable rainfall. Such variations can have great negative impact on agricultural productivity, especially in areas that significantly depends on the monsoon. While insufficient rainfall can cause low agricultural productivity at the harvesting time, excessive rainfall can cause water logging, soil erosion, and agricultural damage at the same time. In Cooch Behar district a large portion of farmers depend on traditional farming practices and insufficient irrigation infrastructure, rainfall variability can cause uncertainty in agricultural productivity and economic stability.

Although the district has high average rainfall, still there are some serious questions about the viability of agricultural output given the fluctuating pattern and unpredictable precipitation. As a result, understanding

the features and consequences of rainfall variability in Cooch Behar district is crucial to understanding the challenges that the traditional farmers are facing every day.

The main purpose of this study is to understand the relationship between the agricultural productivity in the Cooch Behar district and rainfall productivity. It aims to examine how variations in rainfall patterns over time affect crop yield, production, and overall area agricultural outcomes. The study intends to highlight the importance of climate-resilient and adaptable farming techniques and provide insight into the challenges faced by farmers through a qualitative examination of rainfall patterns and agricultural output.

LITERATURE REVIEW

It has long been known that one of the most important meteorological elements affecting agricultural production is rainfall variability, especially in monsoon-dependent nations like India. Numerous empirical studies conducted in the nation's various agro climatic zones have looked at the connection between variations in rainfall and crop productivity, demonstrating how sensitive agricultural systems are to both the quantity and distribution of rainfall.

Bowden, Foster, and Parkes (2023) used machine learning approaches to examine rice production and monsoon variability in the Indo-Gangetic Plains at a larger spatial scale. Their results showed that changes in rice yield and harvested area may be considerably explained by solar radiation, rainfall amount, and the frequency of wet days. The study underlined that agricultural performance is significantly influenced by both the overall amount of rainfall and its intra-seasonal distribution. In support of this, a national study that was published in Climate Services (2023) looked at the temporal and spatial variability of Indian Summer Monsoon Rainfall and how it affected the country's main kharif crops. The study demonstrated that climatic anomalies had a significant impact on district-level crop productivity throughout India, especially during El Niño years.

Khedikar, Panchabhai, and Mandal (2023) investigated how rainfall variability affected cotton and Tur (arhar) crop yield in different Maharashtra areas. Their research showed that crop development and yields are greatly impacted by variations from typical rainfall levels. Depending on the crop stage, it was discovered that both insufficient and excessive rainfall had a negative impact on productivity, indicating that the timing and distribution of rainfall are just as crucial as the overall amount of rainfall. In a similar vein, Ramanjineyulu *et al.* (2021) measured the impact of seasonal rainfall variability in their study on pearl millet in Tamil Nadu's Madurai district and discovered that

extreme rainfall conditions, either above-normal or below-normal, reduced yields. These results highlight how susceptible rain-fed crops are to fluctuations in rainfall.

Jena *et al.* (2025) examined the effects of meteorological variability on crop yields and land use dynamics in Odisha, with a particular focus on eastern India. Their findings showed that variations in rainfall had a short- and long-term detrimental impact on grain yields, as well as influencing cropping intensity and land-use choices. This implies that variations in rainfall have an impact on both agricultural productivity and structural elements. Similar findings were made by Lakshmi, Thomas, and Joseph (2024), who studied the Wayanad area in Kerala and discovered that changes in the timing and intensity of rainfall had a substantial impact on agricultural production as well as the availability of water resources, making rain-fed farming systems more vulnerable.

Additional information is provided by region-specific research conducted in West Bengal. In their analysis of rainfall patterns and rice production in the Bankura area, Chakraborty *et al.* (2025) noted rising monsoon rainfall with significant temporal variability. According to the study, rice yields are decreased by both insufficient and excessive rainfall, underscoring the dangers rain-fed agriculture faces as a result of changing climate conditions. In their analysis of West Bengal's several agro-climatic zones, Pramanick and Pal (n.d.) also noted diminishing rainfall trends in a number of locations, along with inconsistent impacts on rice productivity. According to their findings, irrigation infrastructure, technology adoption, and other inputs all have a moderating effect on yield outcomes; therefore rainfall alone does not predict them.

In the Solapur area of Maharashtra, Ubale and Kamble (2025) found a high association between jawar crop yields and annual rainfall variability, further supporting the rainfall–productivity relationship. Their geographic research showed that agricultural productivity is greatly decreased by unequal rainfall distribution. Furthermore, Ghosh, Mukhoti, and Sharma (2025) integrated rainfall variability into rice production prediction models and discovered that taking rainfall risk into account increases the accuracy of yield forecasts, highlighting the significance of rainfall variability in agricultural planning and policy development.

Overall, the existing literature consistently indicates that rainfall variability—whether in terms of total volume, seasonal distribution, or extreme events—plays a crucial role in determining agricultural productivity across India. However, while several studies have focused on Maharashtra, Tamil Nadu, Odisha, Kerala, and parts of West Bengal such as

Bankura, limited research has specifically examined the rainfall–agricultural productivity relationship in Cooch Behar district. Given its dependence on monsoon rainfall and its distinct agro-climatic characteristics within North Bengal, a focused study on rainfall variability and agricultural productivity in Cooch Behar district is both relevant and necessary. The present study seeks to address this gap by examining seasonal rainfall patterns and their association with agricultural output over the recent decade.

Research Gap

Although a lot of research has been done on states like Maharashtra, Tamil Nadu, Odisha, Kerala and specific districts of West Bengal like Bankura and examined the relationship between rainfall variability and agricultural productivity across different regions of India. These studies primarily focus on monsoon variability, crop-specific impacts, at national or regional scales, or employ advanced modeling techniques to evaluate rainfall–yield connections. But, for the northern region of West Bengal, specifically the district of Cooch Behar, there is a conspicuous absence of district-level, seasonally disaggregated information. Because Cooch Behar is primarily an agrarian region that depends significantly on monsoon rainfall, localized seasonal variations in rainfall may have unique effects on agricultural output and crop performance.

Furthermore, these existing studies often emphasize only quantitative approaches, while some limited research has been done on descriptive seasonal trend analysis that captures recent decadal patterns and ground-level agricultural dynamics. Therefore, to fill this regional and contextual research gap, a focused study that looks at rainfall variability and its relationship to agricultural productivity in the Cooch Behar district over the past ten years is necessary. The present study aims to address this gap by analyzing seasonal rainfall patterns and corresponding agricultural output trends to provide region-specific insights.

Due to its agro-based economy and high dependency on monsoon rains, Cooch Behar district especially significant. The district has some significant features like fertile alluvial soil, intensive cultivation of paddy, jute, and other seasonal crops, and a predominantly rural population engaged in agriculture. Because of geographical location in the sub-Himalayan plains, the district has irregular rainfall patterns, flooding, and seasonal climatic fluctuations. During the critical planting and harvesting times variability in rainfall can have a big impact on crop productivity and farmers income. Despite these unique socio-economic and agro-climate characteristics, there is still absence of rigorous studies relating Cooch Behar's agricultural output to seasonal rainfall variations. Therefore, it is both necessary and timely to carry out conducting a

focused study in this district for generating region-specific insights that can support local agricultural planning and climate adaptation strategies.

Objectives of the Study

1. To examine the trend of seasonal and annual rainfall in Cooch Behar district.
2. To examine the trend of agricultural production of major crops in Cooch Behar district.
3. To understand how seasonal variations in rainfall influence agricultural productivity in the district.
4. To analyze the overall impact of rainfall fluctuations on agricultural performance in Cooch Behar district.

RESEARCH METHODOLOGY

1. Research Design: To explore the relationship between rainfall variability and agricultural productivity in the Cooch Behar district, West Bengal, this study adopts a descriptive and analytical research approach. The study mainly depends on trend analysis and seasonal comparison. It attempts to systematically evaluate the relationship between rainfall patterns and trends in agricultural output. The study also tries to comprehend how rainfall variations impact district-level agricultural production, making it explanatory in character.

2. Study Area: The present study is conducted in Cooch Behar district, which is located in the northern part of West Bengal in the sub-Himalayan plains. Due to its geographical location and climatic conditions, the district is often exposed to irregular rainfall patterns, water logging, and occasional flooding, which directly affect crop production. The district is featured by fertile alluvial soil and a predominantly agrarian economy. The majority of the rural population works in agriculture, and the district's principal crops include vegetables, paddy, jute, and maize. Cooch Behar district is featured by humid subtropical climate, where agriculture mainly depends on rainfall on monsoon. The majority of its rainfall comes from the monsoon season, while winter and pre-monsoon rainfall remain comparatively low. Therefore, Cooch Behar provides a relevant and significant setting for studying rainfall variability and agricultural productivity.

3. Nature and Sources of Data: The present study has examined based on secondary data resources which is collected from various government sources. Seasonal and annual data has been collected from the Indian Meteorological Department (IMD), the District Statistical Handbook of Cooch Behar, and other official meteorological publications. To analyze seasonal variability, rainfall data has been classified into pre-monsoon, monsoon, post-monsoon. Agricultural data relating to production and productivity of major crops

such as paddy, jute, and maize has been collected from the Department of Agriculture, Government of West Bengal, the District Statistical Handbook, Agricultural Statistics at a Glance, and other official government agricultural databases and reports. These sources ensured the authenticity and reliability of the data used in the study.

4. Variables of the Study: In this study rainfall has been considered an independent variable and agricultural productivity or output of major crops as the dependent variable. To understand the variability over time, rainfall has been examined in both seasonal and annual terms. The variability in rainfall is examined through fluctuations in its timing, distribution, and overall seasonal and annual patterns. On the other hand, agricultural productivity is evaluated by observing changes in crop output and production trends of major crops cultivated in the district. By analyzing how variations in rainfall correspond with changes in agricultural output, the study seeks to understand the extent to which rainfall patterns influence crop productivity in Cooch Behar.

5. Method of Data Analysis

- (a) **Seasonal Analysis:** To understand variations in different agricultural season, rainfall data are divided into seasonal categories. This helps in identifying which season plays a more significant role in affecting crop production.
- (b) **Trend Analysis:** A trend-based approach is used to observe changes in rainfall and agricultural productivity over time. Tables and graphical representations (such as line graphs and bar diagrams) are used to illustrate patterns and fluctuations.
- (c) **Comparative Analysis:** To understand changes in agricultural output, years with high rainfall are compared with years that received low rainfall. This method helps to identify clear relationships between crop performance and changes in rainfall.
- (d) **Growth Pattern and Percentage Change:** Simple percentage change calculations are used to show whether rainfall and agricultural output have increased or decreased over time. This method helps to understand the level of

variation without using complex statistical models.

RESULTS AND DISCUSSION

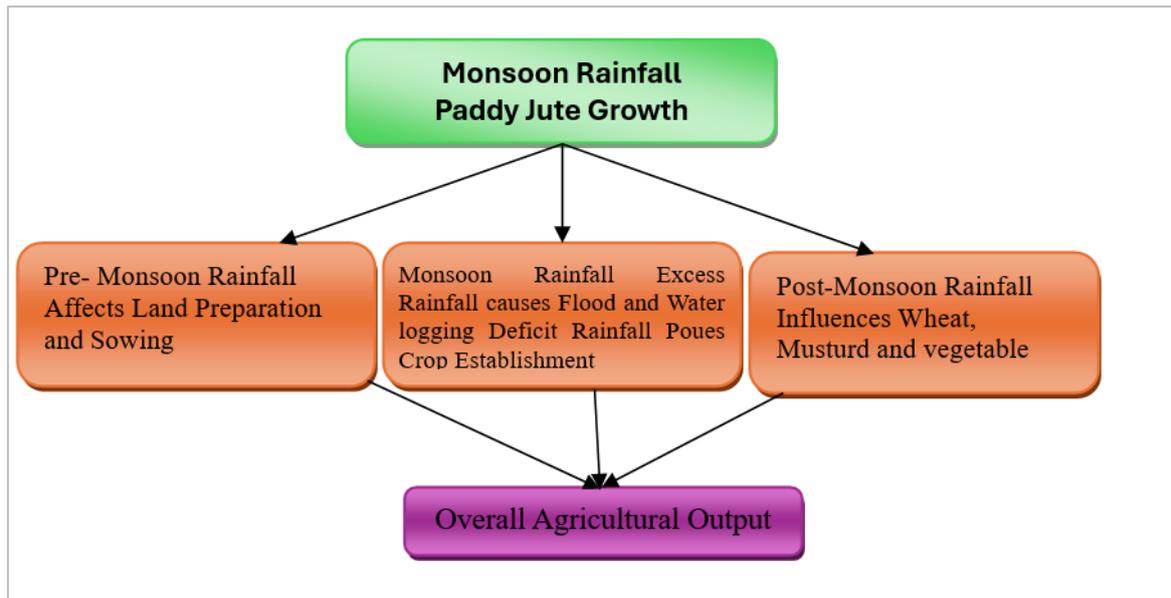
1. Trend of Rainfall Variability in Cooch Behar: The study of secondary rainfall data reveals noticeable seasonal and inter-annual fluctuations in Cooch Behar district. Since Cooch Behar district is located in the foothills of the Eastern Himalayas, it receives relatively high annual rainfall, but the distribution of rainfall is highly uneven. While pre-monsoon and post monsoon seasons show irregular rainfall, the monsoon season contributes the largest share of total rainfall.

It is observed that in many years, due to delayed monsoon the early transplantation of paddy was highly affected. On the other hand, excessive rainfall during peak monsoon months results in water logging and localized flooding. Winter rainfall remains limited and inconsistent, which affects Rabi crops dependent on residual soil moisture. As a result this uneven distribution rather than total annual rainfall appears to be the primary issue influencing agricultural productivity in the district.

2. Seasonal Rainfall and Crop Performance: It is observed that the agricultural in Cooch Behar district is highly seasonal and largely dependent on monsoon rainfall. The findings suggest a strong connection between rainfall timing and crop performance:

- **Kharif Season:** Paddy is the primary cultivation of this season. Timely and moderate monsoon rainfall supports healthy crop growth. However, too much rain frequently submerges fields, which lowers production.
- **Rabi Season:** In this season, crops such as wheat, mustard, and vegetables depend partly on irrigation. Insufficient winter rainfall increases irrigation costs and affects small farmers.
- **Pre-Monsoon Period:** Initial precipitation encourages planting and land preparation. Schedules for agriculture are disrupted by insufficient or delayed rainfall.

Thus, seasonal variability has a direct influence on crop growth stages, from sowing to harvesting shown below in Diagram.



3. Impact of Excess Rainfall and Flooding: Since Cooch Behar district has an extensive river network and receives heavy rainfall during the monsoon season, it is highly vulnerable to flooding. The present study finds that intense rainfall often results in water logging and submergence of agricultural fields, particularly during critical crop stages such as flowering and harvesting. Such conditions lead to significant crop damage and yield reduction. Flooding also contributes to soil erosion and nutrient loss, thereby affecting soil fertility and long-term agricultural sustainability. Small and marginal farmers are disproportionately affected, as they generally lack adequate drainage facilities, financial resilience, and access to crop insurance coverage. Consequently, agricultural productivity in flood-prone blocks remains more unstable and uncertain compared to relatively elevated areas where the risk of water stagnation is lower.

4. Impact of Rainfall Deficiency: Apart from regular heavy rainfall, irregular rainfall also affects agricultural productivity during crucial growth periods. During transplantation and gain-filling stages, irregular monsoon results in insufficient productivity, particularly for paddy. Also due to lack of irrigation, the farmers face several difficulties. They depend on tube wells and pumps, which further increases the production costs. Therefore, both excess and deficit rainfall creates production risks.

5. Farmers' Adaptation Practices: The present study also highlights a number of adaptive measures by the farmers in response to the rainfall unpredictability in this district. In order to deal with irregular monsoon onset and uncertain rainfall distribution, many farmers adjust their sowing and transplanting dates according to prevailing weather conditions. To reduce the chance of crop failure brought on by too much rain or a delayed monsoon, there has also been a slow move toward the

adoption of crop varieties that are short-duration and flood-resistant. Farmers are depending more and more on supplemental watering to save standing crops during times of insufficient rainfall or protracted dry spells. To lessen their reliance on a single crop that is sensitive to the monsoon, some growers have also expanded into the production of vegetables and other alternative crops.

6. Overall Effect on Agricultural Productivity: The overall study suggests that although the rainfall has an effect on agricultural productivity in Cooch Behar district but rainfall timing, intensity, and distribution have a greater impact. While years with well-distributed rainfall show relatively stable output, years with extreme events—either flood or drought-like conditions—exhibit reduced and unstable agricultural output. The study finds that for small and marginal farmers, rainfall variability creates uncertainty in agricultural income and livelihood security.

Crop-wise Impact of Rainfall Variability

1. Impact on Paddy (Rice): The primary crop in Cooch Behar district is Paddy and it is highly dependent on monsoon rainfall. Since rice cultivation requires standing water during the early growth stage, adequate and timely rainfall is essential. The findings suggest that delayed monsoon rainfall results in transplantation activities, which leads to reduced plant growth and productivity, but excessive rainfall often causes water logging and flooding, especially in low-lying areas, damaging seedlings and affecting grain formation. When monsoon rainfall arrives on time and remains moderate, paddy production remains stable and satisfactory. As a result, paddy production in the district is highly sensitive not only to the amount of rainfall but also to its timing and intensity.

2. **Impact on Jute:** Another important crop in Cooch Behar district is Jute, which grown particularly during pre-monsoon and early-monsoon season. This crop requires moderate rainfall with warm and humid climatic conditions. The study shows that moderate and evenly distributed rainfall supports proper fiber development. However, excessive rainfall during the retting process creates difficulties in maintaining water quality, affecting fiber quality. On the other hand, irregular rainfall during the early growth stage affects plant height and fiber strength. As a result, both the quantity and quality of Jute production is highly affected by rainfall variability.
3. **Impact on Wheat:** Wheat has less dependency on monsoon rainfall as it is mainly cultivated during the Rabi season. But, residual soil and winter rainfall moisture can affect its growth. The result finds that irregular winter rainfall increases dependence on irrigation. Small farmers who do not have proper irrigation facilities face reduced productivity. Excessive unseasonal rainfall during the harvesting stage may damage the crop and reduce grain quality. Hence, even though wheat is not fully rain-dependent, irregular winter rainfall significantly affects its output.
4. **Impact on Mustard:** Another important Rabi crop is Mustard, which also very sensitive rainfall during flowering and seed formation stages. The study finds that heavy rainfall during flowering leads to damages seed formation.
5. **Impact on Vegetables:** In recent years vegetable cultivation has increases in Cooch Behar as a source of income diversification and vegetables are generally more sensitive to climatic fluctuations. Seasonal variability also affects market supply, leading to price fluctuations. Excess rainfall leads to water logging, root diseases, and crop damage, while insufficient rainfall during critical growth stages reduces yield and quality. As a result, farmers who are engaged in vegetable cultivation face higher production risks due to rainfall irregularity.
6. **Comparative Crop Sensitivity:** According to the overall findings, different crops in the Cooch Behar district show different levels of sensitivity to rainfall variability. Due to its strong need on timely and sufficient monsoon water for transplantation, vegetative development, and grain formation, paddy stands out among the major crops as the most rainfall-sensitive. Rainfall distribution and the availability of ideal water conditions,

especially during the retting process, have an impact on jute cultivation in addition to its quantity. The availability of winter rainfall and unforeseen or unseasonal showers have a major impact on wheat and mustard, which are predominantly grown in the winter and can harm crops during the flowering or harvesting stages. Vegetable crops are found to be highly vulnerable to both excess and deficient rainfall, as they require balanced moisture conditions and are easily damaged by water logging or drought stress. Therefore, rainfall variability does not uniformly affect all crops; its impact differs according to crop type, seasonal requirements, and specific growth stages.

SUGGESTIONS

On the basis of the above findings, the following policy measures are suggested:

1. **Improvement of Irrigation Infrastructure:** Dependency on uncertain rainfall can be reduced by expanding minor irrigation facilities, especially in rained areas. Promotion of community-based irrigation systems and efficient water management practices will help stabilize crop production.
2. **Development of Drainage and Flood Control Systems:** As Cooch Behar is flood-zone area, so increasing drainage systems and canals can reduce crop damage during heavy rainfall. Proper water management during peak monsoon months is essential to minimize agricultural loss.
3. **Promotion of Climate-Resilient Crop Varieties:** Government and agricultural research institutions should promote short-duration, drought-resistant, and flood-tolerant crop varieties suitable for the agro-climatic conditions of the district.
4. **Crop Diversification:** Encouraging diversification into less rainfall-sensitive crops and high-value vegetables can reduce risk and enhance farmers' income stability.
5. **Weather Advisory and Early Warning System:** Strengthening local weather forecasting and dissemination of timely agricultural advisories can help farmers adjust sowing and harvesting schedules according to rainfall patterns.
6. **Crop Insurance Awareness:** Increasing awareness and accessibility of crop insurance schemes can protect farmers from financial loss due to rainfall-related crop damage.

CONCLUSION

The present study looked at the connection between agricultural output and rainfall variability in Cooch Behar district. The study highlights that agriculture in the district is highly dependent on seasonal rainfall patterns, particularly the monsoon. Despite the region's relatively high yearly rainfall, agricultural production is greatly impacted by its

uneven distribution, erratic timing, and rising frequency of catastrophic events like floods and dry spells. According to the study, paddy cultivation is most vulnerable to monsoon irregularities, while jute, wheat, mustard, and vegetables are affected differently depending on seasonal rainfall behavior. Both excess rainfall and rainfall deficiency create production risks, affecting crop yield, quality, and stability. Flooding and water logging damage standing crops, while insufficient rainfall increases irrigation dependency and production costs.

Overall, the study concludes that it is the timing, intensity and seasonal distribution in the district that affect agricultural productivity more than quantity of rainfall. Rainfall variability has emerged as a critical factor influencing crop output and farmers' livelihood security in the district.

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