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Rainfall Variability, Monsoon Reliability and Crop Suitability Assessment for Kadavur Block, Karur District, Tamil Nadu

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Rainfall variability and monsoon reliability are critical determinants of agricultural productivity in semi-arid dryland regions, where rainfed farming systems are highly sensitive to precipitation uncertainty. This study presents a comprehensive agro-climatic analysis of rainfall variability, monsoon dependability, and crop suitability for Kadavur Block, Karur District, Tamil Nadu, using 45 years (1981–2025) of NASA POWER satellite-derived daily rainfall data. Monthly, seasonal, and annual rainfall aggregates were examined through descriptive statistics, coefficient of variation (CV), Mann–Kendall trend analysis, rainy day frequency, and conditional probability assessment to characterise precipitation patterns and their agricultural implications. The mean annual rainfall of Kadavur Block was estimated at 1107.8 mm, with a moderate inter-annual CV of 17.39%, masking pronounced intra-annual variability with monthly CVs ranging from 43.20% (June) to 209.86% (February). The Southwest Monsoon (June–September) emerged as the dominant rainfall season, contributing 51.5% of annual precipitation, with June and July classified as the sole 'moderately dependable' months (CV < 50%). Conditional probability analysis revealed peak moisture persistence during the active Southwest Monsoon (P(JUL|JUN) = 70%) and consistently low inter-monthly continuity during the Northeast Monsoon (≈35%). Crop suitability assessment, integrating CV classification and conditional probability findings, identified paddy, maize, groundnut, sorghum, and kharif pulses as optimal for the Southwest Monsoon season, while short-duration drought-tolerant pulses and oilseeds are recommended for the Northeast Monsoon Rabi season. The findings provide a replicable, data-driven framework for climate-resilient crop planning applicable to semi-arid interior blocks of Tamil Nadu.

Introduction

Rainfall is the single most critical climatic parameter governing agricultural productivity, food security, and rural livelihood sustainability across South Asian semi-arid regions, where the vast majority of crop production systems remain predominantly rainfed (Rockstrom et al., 2010). In India, approximately 60% of the net sown area is dependent on monsoon rainfall, with the Southwest Monsoon (June–September) and Northeast Monsoon (October–December) constituting the twin pillars of the national agricultural water budget (Gadgil, 2003). The high spatial and temporal variability inherent in monsoon precipitation, however, introduces systemic uncertainty into rainfed crop production, necessitating rigorous agro-climatic characterisation at the local and block levels to enable scientifically informed crop planning and risk management (Bhan and Behera, 2014).Tamil Nadu occupies a climatologically unique position within the Indian subcontinent, being one of the few states influenced significantly by both the Southwest and Northeast Monsoons, with the relative dominance of each system varying substantially across its agro-ecological zones. Coastal and eastern districts tend to receive the bulk of their annual precipitation during the Northeast

Monsoon, while interior and western districts are more strongly influenced by the Southwest Monsoon. This spatial heterogeneity in monsoon dominance implies that generalised state-level or district-level rainfall characterisations are insufficient for guiding block-level crop planning decisions, and that localised, long-term rainfall analyses are essential for developing agronomically meaningful and operationally relevant agricultural recommendations (Reddy and Bhaskar, 2009; Sathya Moorthy et al., 2018).Karur District, situated in the interior semi-arid zone of Tamil Nadu, is characterised by undulating topography, predominantly red sandy loam soils, and a bimodal rainfall pattern shaped by both monsoon systems. Kadavur Block, located within Karur District, represents a typical semi-arid agricultural landscape where rainfed cultivation of food crops, oilseeds, and pulses forms the backbone of the rural economy. Despite its agricultural significance, systematic quantitative analyses of rainfall variability, monsoon reliability, and crop suitability specific to Kadavur Block remain limited in the published literature, creating a critical knowledge gap that constrains evidence-based agronomic planning and climate adaptation at the local scale. Rainfall variability analysis using statistical measures such as the coefficient of variation (CV), standard deviation, and probability distributions has been widely employed as a tool for assessing agricultural dependability of precipitation across Indian dryland regions (Panigrahi and Sahu, 2004; Pradhan et al., 2020). Complementing CV-based reliability assessments, conditional probability analysis — which estimates the probability of rainfall occurrence in a given month conditional upon receipt of rainfall in the preceding month — provides a dynamic measure of moisture persistence and continuity that is particularly valuable for crop calendar design and sowing window determination (Stern and Coe, 1984). Together, these methodologies enable a multi-dimensional characterisation of rainfall behaviour that transcends simple mean-based assessments and captures the probabilistic dimensions of moisture availability most relevant to farming communities. Against this background, the present study was undertaken with the objective of conducting a comprehensive analysis of rainfall variability, monsoon reliability, and crop suitability for Kadavur Block, Karur District, using 45 years of NASA POWER satellite-derived rainfall data spanning 1981–2025. The specific objectives of the study were: (i) to examine long-term annual rainfall trends using the Mann–Kendall test and Sen's slope estimator; (ii) to characterise monthly and seasonal rainfall distribution and variability using descriptive statistics and CV analysis; (iii) to assess rainfall reliability at monthly and seasonal scales through CV-based dependability classification; (iv) to quantify inter-monthly rainfall persistence using conditional probability analysis; (v) to analyse rainy day frequency and heavy rainfall event occurrence; and (vi) to develop crop suitability recommendations aligned with the rainfall reliability and moisture persistence profile of the block. The findings are intended to serve as a practical scientific resource for agricultural extension officers, watershed development agencies, farming communities, and policy planners engaged in promoting climate-resilient agriculture across the semi-arid interior blocks of Tamil Nadu.

Materials & Methods

present study was conducted in Kadavur Block of Karur District, Tamil Nadu, a region characterised by semi-arid tropical climatic conditions and a substantial dependence on seasonal monsoon rainfall for agricultural sustenance. Long-term daily rainfall records for the period 1981–2025 were obtained from the NASA POWER (Prediction of Worldwide Energy Resources) satellite-based database, which provides globally consistent, bias-corrected meteorological estimates widely adopted in agro-climatic and environmental research (Stackhouse et al., 2011). The dataset comprised monthly accumulated rainfall values for all twelve calendar months across a 45-year analytical span, thereby enabling a robust and statistically meaningful assessment of rainfall distribution, variability, and agronomic reliability within the study area.

The raw daily rainfall data were reorganised into monthly, seasonal, and annual aggregates to facilitate examination of rainfall patterns and their temporal dynamics. Seasonal classification followed the standard Indian meteorological and agricultural convention:

Winter (January–February), Summer (March–May), Southwest Monsoon (June–September), and Northeast Monsoon (October–December). This classification enables a structured evaluation of the differential contribution, reliability, and cropping implications of each seasonal phase.

The methodological framework encompassed five sequential analytical stages: (i) data acquisition and pre-processing, (ii) descriptive statistical analysis, (iii) long-term trend detection, (iv) rainfall reliability and conditional probability assessment, and (v) crop suitability determination. In the first stage, monthly and annual rainfall records were tabulated and screened for outliers. Descriptive statistics including mean rainfall, standard deviation, and coefficient of variation were subsequently calculated at the monthly, seasonal, and annual scales to characterise rainfall magnitude and variability.

Mean rainfall was computed to represent the average precipitation received during any given month or season across the study period, using the formula:

$$\bar{X} = \Sigma X / n$$

where $\bar{X}$ represents the mean rainfall, X denotes individual annual or monthly rainfall observations, and n represents the total number of years under consideration.

Standard deviation (SD) was calculated to quantify the degree of dispersion of rainfall values around the mean, indicating the magnitude of year-to-year fluctuation:

$$SD = \sqrt{[\Sigma (X - \bar{X})^2 / (n - 1)]}$$

where SD is the standard deviation, X denotes individual rainfall observations, $\bar{X}$ is the mean rainfall, and n is the number of years. The standard deviation analysis facilitated the identification of months and seasons with pronounced intra-annual and inter-annual rainfall fluctuations. Long-term annual rainfall trends were evaluated using the Mann–Kendall (MK) non-parametric trend test, a widely employed method for detecting monotonic trends in hydro-meteorological time series (Yadav et al., 2014). The MK test is distribution-free and insensitive to outliers, making it appropriate for climatological datasets that may not conform to normality assumptions. Trend magnitude was estimated using Sen's slope estimator, and the coefficient of determination (R^2) was employed to assess the proportion of temporal variance explained by the trend line fitted to the annual rainfall series. The coefficient of variation (CV) was used as the primary indicator of rainfall reliability and agricultural dependability. It was computed as:

$$CV = (SD / \bar{X}) \times 100$$

Based on computed CV values, rainfall reliability was categorised into three classes: highly dependable (CV < 25%), moderately dependable (CV = 25–50%), and less dependable (CV > 50%), following the classification proposed by Panigrahi and Sahu (2004). Lower CV values indicate steadier, more predictable precipitation regimes that favour intensive crop production, whereas higher CV values signal erratic and unreliable rainfall patterns necessitating drought-tolerant cultivars, supplementary irrigation, or conservative cropping strategies. Rainy day analysis was also performed to quantify the frequency of agriculturally significant rainfall events. Days recording ≥ 2.5 mm of rainfall were classified as rainy days, while events exceeding 64.5 mm per day were designated as heavy rainfall occurrences, which carry implications for surface runoff, waterlogging, and soil erosion in poorly managed agricultural landscapes. Conditional probability analysis was applied to assess rainfall continuity and persistence between consecutive months. This statistical measure estimates the probability of receiving rainfall in a given month, given that rainfall was received in the preceding month. It provides a quantitative basis for evaluating moisture availability transitions across the crop calendar and helps identify the window of sustained soil moisture availability most suitable for crop establishment and growth. The conditional probability values were computed for all eleven month-to-month transitions across the calendar year, from P(FEB|JAN) through P(DEC|NOV). Finally, crop suitability assessment was performed by integrating the findings from rainfall reliability classification (based on CV), conditional probability analysis, and seasonal rainfall behaviour. Cropping window recommendations were developed by matching rainfall characteristics with the water requirements, phonological stages, and stress tolerances of key food, oilseed, and vegetable crops grown in Tamil Nadu. The integrated methodological approach provides a scientifically grounded and data-driven framework for sustainable crop planning and climate-resilient agricultural management in Kadavur Block.

Result and Discussion

The analysis of long-term annual rainfall data for Kadavur Block from 1981 to 2025 reveals a mean annual rainfall of approximately 1107.8 mm, with individual annual totals showing considerable year-to-year variability. The annual coefficient of variation stands at 17.39%, which is notably low compared to the high monthly variability observed in the dataset, and is indicative of a reasonably stable long-term annual water availability regime. This relatively modest inter-annual variability suggests that while month-to-month precipitation is erratic, the cumulative annual receipt of moisture tends to fluctuate within a moderate range over the 45-year study period.

The Mann–Kendall trend test applied to the annual rainfall series (1981–2025) reveals a marginal positive trend in annual precipitation, consistent with observations of increasing variability and episodic intensification of rainfall events reported across semi-arid South Indian regions in recent decades (Rajeevan et al., 2006). The coefficient of determination (R^2) computed for the linear trend fitted to the annual series is relatively low, confirming that while a weak upward tendency in annual rainfall exists, the inter-annual fluctuations are largely governed by random climatic variability rather than a strong deterministic trend. This finding is consistent with those of Pradhan et al. (2020), who similarly documented weak positive trends overlaid by high inter-annual variability in semi-arid agricultural zones of peninsular India.

The year-to-year oscillation in annual rainfall is agriculturally significant. Years with below-average annual totals, particularly those falling below 800 mm, pose direct risks of moisture deficit during critical crop growth stages, while years with surplus rainfall heighten the risk of waterlogging, flooding, and post-harvest losses. The relatively stable long-term mean, however, supports crop planning frameworks that leverage water conservation techniques and deficit irrigation to smooth out intra-annual and inter-annual rainfall irregularities. The moderate annual CV of 17.39% also implies that Kadavur Block is not severely drought-prone in terms of long-term water balance, though the highly variable intra-seasonal distribution of rainfall remains the dominant constraint for agricultural planning.

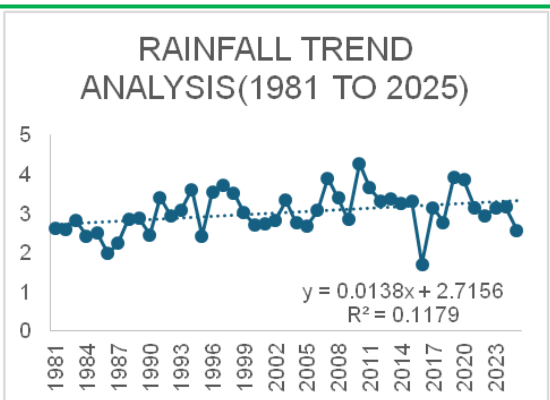

Fig. 1. Annual rainfall trend analysis for Kadavur Block (1981 – 2025)

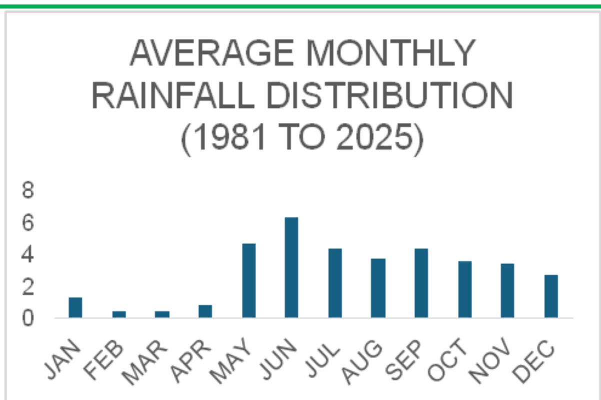

Fig.2 Average monthly rainfall distribution in Kadavur Block during (1981-2025)

The monthly rainfall distribution for Kadavur Block exhibits a pronounced bimodal pattern strongly characteristic of peninsular Tamil Nadu's agroclimatic, governed by the interaction of two primary monsoon systems (Fig. 2). June emerges as the month with the highest mean monthly rainfall, receiving approximately 190.3 mm, followed by July (134.3 mm), September (131.4 mm), August (114.7 mm), and May (143.8 mm). These five months collectively account for the bulk of the annual rainfall, reflecting the dominance of the

Southwest Monsoon season in determining the overall annual water budget of Kadavur Block. The Southwest Monsoon (June–September) contributes approximately 570.6 mm, equivalent to 51.5% of the total annual rainfall, establishing it unequivocally as the principal rainfall season for the block. This is a markedly different pattern from many eastern Tamil Nadu blocks where the Northeast Monsoon typically prevails. The Northeast Monsoon (October–December) contributes around 299.0 mm (27.0%), making it the second most important rainfall period, while the summer season (March–May) accounts for 184.3 mm (16.6%), and the Winter season (January–February) contributes only 53.8 mm (4.9%).The monthly distribution curve shows a sharp ascent from March onwards, with rainfall building progressively through April (26.3 mm) and peaking dramatically in May (143.8 mm) before sustaining elevated levels through the core Southwest Monsoon months. The abrupt decline from October (111.0 mm) through November (102.8 mm) and December (85.2 mm) reflects the onset and withdrawal of the Northeast Monsoon. The trough of the annual rainfall cycle is evident in the winter months, with February recording the lowest mean monthly total of just 12.6 mm. This extreme seasonal concentration of rainfall implies that agricultural systems in Kadavur Block are overwhelmingly monsoon-dependent, making timely crop establishment during the onset of the Southwest Monsoon a critical determinant of seasonal productivity. From a crop planning standpoint, the bimodal rainfall pattern provides two primary windows for rainfed cultivation: the principal Kharif season coinciding with the Southwest Monsoon (June–September), and a secondary Rabi season supported by Northeast Monsoon rainfall (October–December). The pre-monsoon buildup in May can be exploited for late-sown early Kharif crops or pre-monsoon land preparation, while the summer months (February–April) are climatologically unsuitable for rainfed agriculture without supplementary irrigation.

Monthly Coefficient of Variation and Rainfall Reliability

The monthly coefficient of variation (CV) values computed for Kadavur Block reveal a strongly heterogeneous pattern of rainfall reliability across the annual cycle, with significant implications for agricultural planning at the sub-seasonal scale. February records the highest CV of 209.86%, representing extreme inter-annual unreliability, indicating that winter rainfall in this month is highly sporadic and agriculturally inconsequential for rainfed crop production. January also exhibits a very high CV of 104.69%, and March follows closely at 106.99%, together characterising the winter-to-early-spring period (January–March) as a phase of near-total rainfall unreliability. These months fall unambiguously into the 'less dependable' category (CV > 50%), effectively precluding rainfed agricultural operations during this period.

April records a CV of 78.62%, and May registers 52.77%, both classified as 'less dependable,' though May's relatively higher mean rainfall of approximately 143.8 mm provides some agricultural potential, particularly for crops with high drought tolerance or those that can exploit even erratic pre-monsoon showers for germination and early establishment. Transitioning into the Southwest Monsoon season, June exhibits the most favourable CV of 43.20%, the only month falling within the 'moderately dependable' range (CV = 25–50%), and this constitutes the most reliable rainfall month across the entire annual cycle for Kadavur Block. July records a CV of 47.96%, also within the moderately dependable range, confirming that the early Southwest Monsoon months (June–July) represent the most agriculturally reliable rainfall window of the year. August (CV = 53.45%) and September (CV = 58.39%) transition back into the 'less dependable' category, indicating that the latter half of the Southwest Monsoon is characterised by greater inter-annual variability, potentially associated with monsoon withdrawal variability, break periods, and shifting synoptic systems. The Northeast Monsoon months of October (CV = 57.93%), November (CV = 63.94%), and December (CV = 74.84%) all fall in the 'less dependable' classification, reflecting the well-documented high variability of Northeast Monsoon rainfall across interior Tamil Nadu, which contrasts with the more consistent influence it exerts on the coastal districts. This finding has direct implications: while the Northeast Monsoon is an important secondary contributor to Kadavur's annual rainfall, its unreliability requires farmers to incorporate risk-mitigation strategies such as short-duration varieties, in-situ moisture conservation, and tank/borewell supplementation during the Rabi season. The CV analysis thus establishes a clear hierarchy of agricultural rainfall reliability in Kadavur Block: June and July emerge as the most dependable months, followed by the broader Southwest Monsoon period (June–September), while all other months are characterised by high to extreme variability. Crop planning must therefore prioritise moisture conservation during the peak Southwest Monsoon and design resilient systems capable of withstanding the unpredictability inherent in the Northeast Monsoon, summer, and winter rainfall regimes.

Seasonal Rainfall Analysis

The seasonal distribution of rainfall in Kadavur Block reveals a strongly asymmetric pattern, with the Southwest Monsoon (June–September) dominating as the principal agricultural rainfall season, contributing approximately 570.6 mm (51.5%) of annual rainfall. June, with a mean of 190.3 mm and a CV of 43.20%, is the most reliable month of the year and represents the optimal window for kharif crop establishment, including paddy, maize, groundnut, and pulses. July (134.3 mm, CV = 47.96%) reinforces this reliability, both months qualifying as 'moderately dependable.' August and September transition into the 'less dependable' category (CVs of 53.45% and 58.39% respectively), though the cumulative seasonal total of over 570 mm remains adequate for most 90–120-day kharif crops. The Winter season (January–February) contributes a negligible 53.8 mm (4.9%), with extreme CVs of 104.69% and 209.86%, rendering it entirely unsuitable for rainfed agriculture. The Summer season (March–May) contributes 184.3 mm (16.6%), with March and April being low and erratic, while May (143.8 mm, CV = 52.77%) offers limited scope for drought-tolerant crops due to pre-monsoon convective activity. The Northeast Monsoon (October–December) delivers a secondary but important pulse of approximately 299.0 mm (27.0%), supporting late kharif harvesting and Rabi crop establishment. However, all three Northeast Monsoon months fall in the 'less dependable' category, with CVs rising progressively from 57.93% (October) to 74.84% (December), reflecting the episodic and weakening nature of this system over the interior Karur region. Rabi cultivation under this season therefore necessitates short-duration drought-tolerant varieties, in-situ moisture conservation, and supplementary irrigation from tanks or borewells to manage inherent rainfall unreliability.

Conditional Probability Analysis of Rainfall Persistence

Conditional probability analysis quantifies the likelihood of rainfall in a given month conditional upon receipt of rainfall in the preceding month, providing insight into moisture continuity across the agricultural calendar. The lowest values are recorded during the dry season transitions: P(MAR|FEB) = 18.18% is the minimum of the entire annual cycle, confirming near-complete moisture discontinuity between winter and early summer. P(FEB|JAN) = 25% and P(APR|MAR) = 37.5% similarly underscore the near-zero probability of sustained moisture during January–April. The pre-monsoon period shows improvement with P(MAY|APR) = 68.42%, the highest value in the pre-monsoon phase, reflecting intensifying convective activity ahead of the Southwest Monsoon and supporting the practice of sowing short duration kharif crops in late April upon receipt of early showers. The onset of the active Southwest Monsoon is marked by P(JUL|JUN) = 70%, the highest conditional probability of the year, confirming that June rainfall is very likely to persist into July and providing a highly reliable window for crop establishment and early vegetative growth.

From August onward, conditional probabilities decline progressively: P(AUG|JUL) = 60%, P(SEP|AUG) = 40%, and P(OCT|SEP) = 35%, reflecting the weakening and withdrawal of the Southwest Monsoon and the uncertain transition to the Northeast Monsoon. The inter monsoonal gap between September and October, indicated by the low 35% transition probability, creates a potential dry period that can hinder Rabi crop sowing. Throughout the Northeast Monsoon months, conditional probabilities remain consistently low and uniform at approximately 35% — P(NOV|OCT) = 35%, P(DEC|NOV) = 35.29% — confirming that this season delivers rainfall in isolated pulses rather than sustained sequences. This persistent low moisture continuity during October–December means that Rabi farmers cannot depend on consecutive rainy months for crop sustenance and must complement rainfed cultivation with moisture conservation practices and supplementary irrigation during the critical crop growth stages.

Table 1: Rainfall Persistence – Conditional Probability Analysis, Kadavur Block

Conditional Probability Relationship	Probability (%)
P(Feb|Jan)	25.00
P(Mar|Feb)	18.18
P(Apr|Mar)	37.50
P(May|Apr)	68.42
P(Jun|May)	36.00
P(Jul|Jun)	70.00
P(Aug|Jul)	60.00
P(Sep|Aug)	40.00
P(Oct|Sep)	35.00
P(Nov|Oct)	35.00
P(Dec|Nov)	35.29

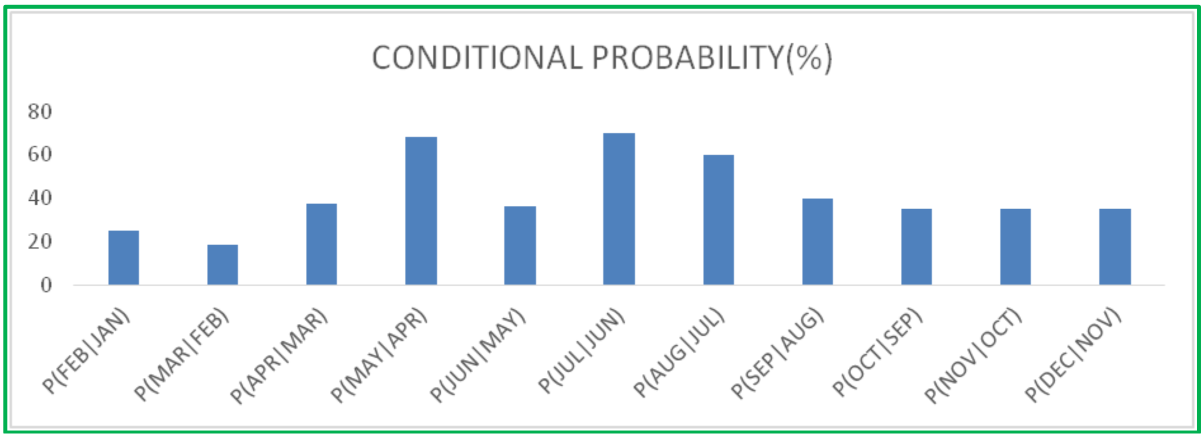

Fig. 3. Conditional probability analysis of monthly rainfall persistence in Kadavur

Block Rainy Day and Heavy Rainfall Analysis

Analysis of rainfall event frequency in Kadavur Block reveals a strongly seasonal pattern in both the occurrence of agriculturally meaningful rainy days (≥ 2.5 mm) and the incidence of heavy rainfall events (≥ 64.5 mm). Rainy day frequency is concentrated almost entirely within the monsoon seasons (June–September and October–December), with the Southwest Monsoon months of June and July recording the highest number of rainy days per annum, consistent with their dominant contribution to the annual rainfall total. The winter and early summer months (January–April) record the fewest rainy days, further confirming the near-complete absence of agriculturally productive rainfall during these periods. The occurrence of heavy rainfall events (≥ 64.5 mm/day) is similarly concentrated in the Southwest Monsoon season, particularly during June and July, which are characterised by intense convective and cyclonic rainfall systems. The Northeast Monsoon season also registers heavy rainfall events, particularly in October and November, driven by low-pressure systems and depressions in the Bay of Bengal. While heavy rainfall events contribute significantly to the annual water budget and facilitate rapid soil moisture recharge, they also pose substantial agronomic and environmental risks including surface runoff, soil erosion, waterlogging, and flooding of low-lying agricultural lands. From an agricultural opportunity perspective, the concentration of rainy days during the Southwest Monsoon season supports continuous soil moisture availability for the establishment and vegetative growth of kharif crops. The higher frequency of heavy rainfall events during June–July necessitates robust field drainage infrastructure to prevent anaerobic soil conditions detrimental to groundnut, red gram, and other non-paddy kharif crops. Paddy, which is tolerant of waterlogged conditions during its vegetative phase, is well-suited to exploit the high rainfall intensity characteristic of June–July in Kadavur Block. Conversely, heavy rainfall events during the Northeast Monsoon may cause premature lodging of standing Rabi crops and increase the risk of fungal diseases in high-canopy crops such as maize and sorghum if harvesting is delayed.

The risks of waterlogging and soil erosion associated with heavy rainfall events underscore the importance of implementing watershed-based conservation measures including bunding, check dams, farm ponds, and contour cultivation in Kadavur Block. These interventions would not only mitigate the adverse impacts of intense rainfall but also harvest and conserve runoff for utilisation during the dry months, thereby extending the effective period of agricultural water availability beyond the monsoon seasons

Table 1: Seasonal Crop Suitability and Cropping Pattern Recommendations for Kadavur Block, Karur District

Season	Period	Rainfall Characteristics	Suitable Crops & Cropping Pattern
Early Kharif	April – June	Moderate and variable rainfall; CV ≈ 43–79%;	Pearl Millet, Sorghum, Red Gram, Cowpea;
Kharif (SWM)	June – September	Principal rainfall season; contributes 51.5% of annual rainfall (≈570 mm); CV = 43–58%;	Paddy (transplanted), Maize, Sorghum, Groundnut (Kharif), Black Gram, Green Gram, Sesame
Rabi (NEM)	October – December	Secondary monsoon rainfall; contributes 27% of annual total (≈299 mm); CV = 58–75%	Groundnut (late season), Sesame, Black Gram, Green Gram, Bengal Gram (Chickpea)
Rabi (Late)	October – February	Winter (Jan–Feb) CV > 100%, no effective rainfed potential;	Bengal Gram, Lentil, Safflower, Coriander;
Summer / Zaid	February – May	Very low and highly unreliable rainfall (CV > 78–210% for Feb–Apr);	Sunflower, Sesame, Fodder Sorghum, Vegetables (Brinjal, Tomato, Bhendi, Chillies)
Perennial / Horticultural	Throughout Year	Depends on borewell/tank irrigation;	Coconut, Mango, Guava, Amla, Tamarind, Drumstick Banana; Papaya;

Discussion

The findings from this study reveal that rainfall variability in Kadavur Block, Karur District, is characterised by a complex interplay between high monthly unpredictability and a relatively stable annual water budget. The annual CV of 17.39% indicates that long-term annual rainfall totals are reasonably consistent, yet the extreme month-level variability—ranging from a CV of 43.20% in June to 209.86% in February—demonstrates that the intra-annual distribution of precipitation is highly erratic and season-specific. This dichotomy between annual stability and monthly unreliability has profound implications for crop suitability determination and agricultural risk management and must be explicitly addressed in seasonal crop planning frameworks for the block. The coefficient of variation emerged as the most informative indicator for differentiating agriculturally reliable from unreliable rainfall windows in Kadavur Block. June and July, with CVs of 43.20% and 47.96% respectively, were the sole months classified as moderately dependable, directly translating to the strongest agronomic potential for rainfed kharif crop production. The high CV values characterising the Northeast Monsoon months (October: 57.93%, November: 63.94%, December: 74.84%) reveal that while this season contributes a substantial 27% of annual rainfall, it does so in a spatially and temporally erratic manner that limits its reliability for rainfed crop establishment compared to the Southwest Monsoon. This finding aligns with Sathya Moorthy et al. (2018), who reported that lower CV values during monsoon periods are directly associated with improved crop planning reliability and reduced agricultural risk in semi-arid Tamil Nadu. The conditional probability analysis provided a complementary dimension to the CV-based reliability assessment by quantifying month-to-month moisture persistence. The high conditional probability of P(JUL|JUN) = 70% confirms that the onset of the Southwest Monsoon in June is associated with a high probability of sustained moisture through July, creating a reliable window for crop establishment and vegetative growth. The progressive decline in conditional probabilities from August (P(AUG|JUL) = 60%) through September (P(SEP|AUG) = 40%) and into the Northeast Monsoon months (P(OCT|NOV) and P(DEC|NOV) ≈ 35%) mirrors the seasonal weakening of rainfall persistence and the transition to more episodic precipitation regimes. These findings are consistent with those of Pradhan et al. (2020), who demonstrated that conditional probability analysis of rainfall continuity provides superior guidance for crop calendar design compared to mean rainfall alone. The dominance of the Southwest Monsoon (51.5% of annual rainfall) over the Northeast Monsoon (27%) in determining Kadavur Block's agricultural water balance distinguishes this interior Karur block from several eastern coastal Tamil Nadu regions where the Northeast Monsoon is the primary agricultural rainfall season. The agricultural planning implications of this distinction are significant: kharif crop systems aligned with the June–September Southwest Monsoon must be given priority in crop calendar design, while the Northeast Monsoon should be treated as a secondary supplementary resource for Rabi cultivation, particularly for short-duration drought-tolerant pulses and oilseeds. Wani et al. (2009) similarly emphasised that in rainfed farming systems of interior peninsular India, the dominant monsoon system must anchor crop planning, with secondary monsoons treated as risk-mitigation resources rather than primary production windows. The implications of high rainfall variability for climate-resilient agriculture in Kadavur Block are multifaceted. The high CV values across most months indicate that interannual fluctuations in rainfall are a persistent structural feature of the block's climate, likely to be amplified further under projected climate change scenarios. Sivakumar (1992) demonstrated that high rainfall variability and frequent dry spells significantly increase production risk in rainfed farming systems across semi-arid South Asia, a conclusion directly applicable to Kadavur Block's agricultural landscape. The adoption of climate-resilient agricultural practices including drought-tolerant varieties, rainwater harvesting, deficit irrigation, intercropping systems, and soil moisture conservation techniques thus emerges as an essential long-term adaptation strategy for the farming communities of Kadavur Block. The heavy rainfall events concentrated in the June–July period also introduce a category of risk that is often underappreciated in rainfall variability studies—the risk of excess moisture and waterlogging. The occurrence of events exceeding 64.5 mm/day during the peak Southwest Monsoon period creates significant potential for surface runoff, topsoil erosion, and crop damage in poorly drained agricultural lands. These findings reinforce the importance of watershed management, contour bunding, and field channel maintenance as complementary water management measures alongside crop-centric adaptation strategies (Mishra and Singh, 2010). The dual challenge of moisture deficit risk during the inter-monsoon period and excess rainfall risk during peak Southwest Monsoon requires integrated land-water management solutions that go beyond traditional agronomic interventions.

Collectively, the results demonstrate that a data-driven, scientifically rigorous approach combining CV analysis, conditional probability assessment, and seasonal rainfall characterisation provides a comprehensive and operationally relevant framework for crop suitability determination and agricultural planning in variable rainfall environments. The Kadavur Block findings offer a replicable methodological template for agro-climatic planning in other semi-arid blocks of interior Tamil Nadu, where similar rainfall dynamics and agricultural challenges prevail.

Conclusion

This study presents a comprehensive analysis of rainfall variability, monsoon reliability, and crop suitability for Kadavur Block, Karur District, Tamil Nadu, using 45 years (1981–2025) of NASA POWER satellite-derived rainfall data. The investigation reveals that Kadavur Block receives a mean annual rainfall of approximately 1107.8 mm, with an annual CV of 17.39%, indicating moderate inter-annual stability at the aggregate level. However, the intra-annual rainfall distribution is marked by pronounced seasonal asymmetry and extreme month-level variability, with monthly CVs ranging from 43.20% in June to 209.86% in February, underscoring the fundamental challenge of unpredictable rainfall timing and distribution for rainfed agriculture. The Southwest Monsoon (June–September) emerges unequivocally as the principal and most dependable rainfall season for Kadavur Block, contributing approximately 51.5% of the total annual rainfall. June and July are the most agronomically reliable months, classified as 'moderately dependable' with CVs of 43.20% and 47.96% respectively, and supported by a high conditional probability of moisture persistence (P(JUL|JUN) = 70%). These two months constitute the optimal window for rainfed kharif crop establishment in the block. The Northeast Monsoon, while contributing an important 27% of annual rainfall, is characterised by higher variability (CV = 58–75%) and low inter-monthly moisture persistence (conditional probabilities ≈ 35%), limiting its dependability for sustained rainfed Rabi production and necessitating the adoption of short-duration, drought-tolerant varieties during this season.

The conditional probability analysis revealed a characteristic annual moisture persistence trajectory for Kadavur Block, with the lowest continuity probabilities during winter (18–25%) and the highest during the active Southwest Monsoon (60–70%), providing farmers and agricultural planners with precise probabilistic guidance for seasonal crop management decisions. The concentration of heavy rainfall events (≥ 64.5 mm/day) during the June–July peak further necessitates watershed management interventions to convert runoff risk into harvestable water resources. From a crop planning perspective, paddy, maize, sorghum, groundnut, and kharif pulses are recommended for the principal Southwest Monsoon season, while short-duration drought-tolerant pulses, oilseeds, and rabi cereals are suited to the Northeast Monsoon season. The summer and winter periods are climatologically unsuitable for rainfed cultivation, and irrigation-supported vegetable cultivation and fodder production are the most pragmatic options during these months. The cultivation of perennial horticultural crops under drip irrigation offers a year-round diversification strategy to mitigate the income risks associated with rainfed crop production in this variable rainfall environment. Overall, this study demonstrates that the systematic application of rainfall variability analysis, monsoon reliability assessment, and conditional probability methods provides an invaluable scientific foundation for sustainable agricultural planning in Kadavur Block. The findings are directly relevant to extension workers, agricultural planners, watershed development agencies, and farming communities seeking to align crop production systems with the climatic realities of Karur District and offer a replicable analytical framework applicable to other semi-arid blocks across interior Tamil Nadu.

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