Kerala’s Agricultural Future: Climate Variability, Yield Trends, and Forecasting

A Data-Driven Policy Report

Author: Keshvan Vijay Rathnam

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An integrated assessment of Kerala’s evolving climate patterns, stagnating agricultural yields, and its gradual transition from a producer to a consumer economy.

Data Sources: IMD | NASA POWER | UPAg | Agriculture Statistics 2023 | Kerala Climate Action Plan 2.0

I. Introduction and Context

The agricultural sector in Kerala, a state renowned for its diverse agro-ecosystems and reliance on monsoon rainfall, stands at a critical juncture. While recent years have demonstrated remarkable economic resilience, particularly post-pandemic, as confirmed by the *Compendium of Agricultural Statistics: Kerala 2023*, this success is overshadowed by increasing climatic vulnerability. The state's farming practices, deeply rooted in its distinct geography, are facing unprecedented pressures from climate variability, including shifting rainfall patterns, rising temperatures, and the increased frequency of extreme weather events.

This report serves as a foundational analysis to inform policy, seamlessly integrating official statistical evidence, the state's strategic climate action framework, and advanced, data-driven diagnostics on crop-climate sensitivities. The core challenge is not simply one of environmental change, but of structural transformation, requiring policymakers to reconcile the need for livelihood sustainability with the imperative of ecological integrity.

The analysis synthesizes three key sources: first, the official statistics detailing the sector's current status and performance; second, the strategic framework provided by the *Kerala State Action Plan on Climate Change 2.0 (2023-2030)*, which outlines the official policy response; and third, a robust machine investigation ('Kerala's Agricultural Future: Climate Variability, Yield Trends, and Forecasting' Notebook) into historical crop yield data, climate anomalies, and future projections. By weaving these threads together, this report aims to provide a clear, accessible, and actionable roadmap for fostering agricultural resilience in the face of a changing climate. The findings underscore that a proactive, data-informed approach, coupled with community participation, is essential to securing the future of Kerala's unique farming heritage.

II. Background

A. The Economic and Social Significance of Agriculture

Kerala's agricultural sector remains a cornerstone of the state's socio-economic fabric, contributing significantly to rural livelihoods, food security, and regional economic stability. The *Agricultural Statistics 2023* publication confirms the sector's tenacity, noting positive growth rates and rising output over recent years, establishing it as one of the most resilient areas of the state's economy following the global public health crisis. This resilience, however, is often built upon complex, informal safety nets, including support from the substantial remittance economy, which can mask underlying structural and environmental fragilities. The statistics compendium serves as the authoritative baseline, providing twenty years of historical data that reflect shifts in cultivation area, production, and productivity across major crops. The data show that while certain cash crops maintain high productivity, the area under food crops, like paddy, continues to face challenges from land conversion and declining profitability, signaling a critical need for intervention.

B. The Policy Landscape: Kerala State Action Plan on Climate Change 2.0

Acknowledging the grave threat posed by climate change, the Government of Kerala approved the revised State Action Plan on Climate Change (SAPCC 2.0) for the period 2023–2030. This document provides the high-level policy mandate, recognizing that the state is highly vulnerable to climate change impacts, particularly in its coastal regions, mountainous areas, and rainfed agricultural lands. The SAPCC 2.0 identifies specific climate risks, including sea level rise, increased cyclonic activity, changes in monsoon intensity, and heat stress, and outlines sectoral strategies to manage them. For the agriculture sector, the plan emphasizes climate-resilient farming, water management, drought adaptation, and the conservation of agro-biodiversity. It shifts the focus from simple mitigation to robust, localized adaptation, making the official policy framework an essential context for evaluating data-driven findings. The plan's objectives are critical: they articulate a policy intention to move beyond coping mechanisms toward proactive, structural adaptation in agricultural practices.

C. The Synthesis Imperative

The current situation creates an imperative for synthesis: official data confirm the sector's current vitality, while the SAPCC 2.0 confirms the strategic intent to manage future climate risk. The missing link is the precise, data-driven understanding of *how* climate variables currently influence specific crop yields and *what* the future holds under changing climate regimes. The machine learning analysis addresses this gap by quantifying the historical correlation between climate anomalies and yield fluctuation, and by generating forecasts that validate the urgency outlined in the state's climate action plan. This integrated approach ensures that policy recommendations are not based merely on general assumptions but are firmly rooted in empirical evidence and predictive modeling.

III. Data and Methods

A. Data Sources and Scope

The analytical study utilized a comprehensive, multi-decadal dataset focusing on Kerala's agriculture. The primary variables included:

1. **Agricultural Yield Data:** Time series data for major crops in Kerala, extending up to the year 2023, reflecting both food and cash crop productivity. This data provides the core dependent variable for forecasting and correlation analysis.
2. **Climate Records:** Long-term time series for key climatic drivers:
   - **Rainfall:** Total monthly and seasonal precipitation.
   - **Temperature:** Mean monthly maximum and minimum temperatures.
   - **Humidity:** Relative humidity levels.
   - **Soil Moisture:** Root-zone soil moisture estimates, a crucial indicator of water stress in agricultural fields.

The historical depth of the data, while substantial, contained missing or incomplete entries, particularly in records prior to the 1980s, which necessitated robust preprocessing to ensure temporal consistency for time series modeling.

B. Data Preprocessing and Transformation

To prepare the disparate datasets for integrated analysis and predictive modeling, the following preprocessing steps were executed:

1. **Normalization and Scaling:** All numerical features were normalized to prevent variables with larger magnitudes from disproportionately influencing model training.
2. **Interpolation:** To address data gaps in the early records, especially for climate variables, standard interpolation techniques were applied to maintain a consistent temporal resolution, a necessary step for effective time series forecasting.
3. **Anomaly Computation:** A critical step involved calculating **climate anomalies**. This process quantifies the deviation of observed monthly or seasonal climate values (e.g., rainfall, temperature) from their long-term historical averages (baselines). This transforms raw data into a measure of stress or deviation, which is often a more direct predictor of yield failure than the absolute climate value itself. Anomalies enable the detection of extreme weather phases, such as sudden wetness, prolonged dryness, exceptionally hot, or unusually cool periods.

C. Analytical and Modeling Framework

The analysis was structured using a sequence of complementary methods, moving from descriptive exploration to classical time-series forecasting:

1. **Exploratory Data Analysis (EDA):** Visual and statistical summaries were used to examine decadal yield trends, highlight inter-annual variability and establish seasonal climate patterns relevant to Kerala's major cropping seasons.
2. **Crop–Climate Correlation Analysis:** Pearson correlation coefficients were computed between crop yields and climate anomalies (rainfall, temperature, humidity, and root-zone soil moisture). This step identified the most influential climatic drivers of yield fluctuations for specific crops.
3. **Time Series Forecasting (ARIMA):** The Autoregressive Integrated Moving Average (ARIMA) model was applied to forecast future yield trajectories based on historical yield data. This provided a baseline, extrapolative forecast against which climate-sensitive interpretations could be compared.
4. **Sensitivity and Break-Year Analysis:** Instead of advanced ML/DL models, the notebook tested the robustness of ARIMA forecasts by applying break-year thresholds (3%, 5%, 10%) to assess how structural shifts and climate variability influence yield projections. This highlighted the fragility of yield stability under different climate scenarios.
5. **Model Diagnostics and Evaluation:** ARIMA model performance was validated through residual analysis, autocorrelation checks, and standard error metrics (MSE, RMSE, and R^2). These diagnostics confirmed that while the ARIMA model captured historical inertia, it also revealed the limits of purely historical extrapolation in the face of climate change.

IV. Results

A. Decadal Trends and Yield Stagnation

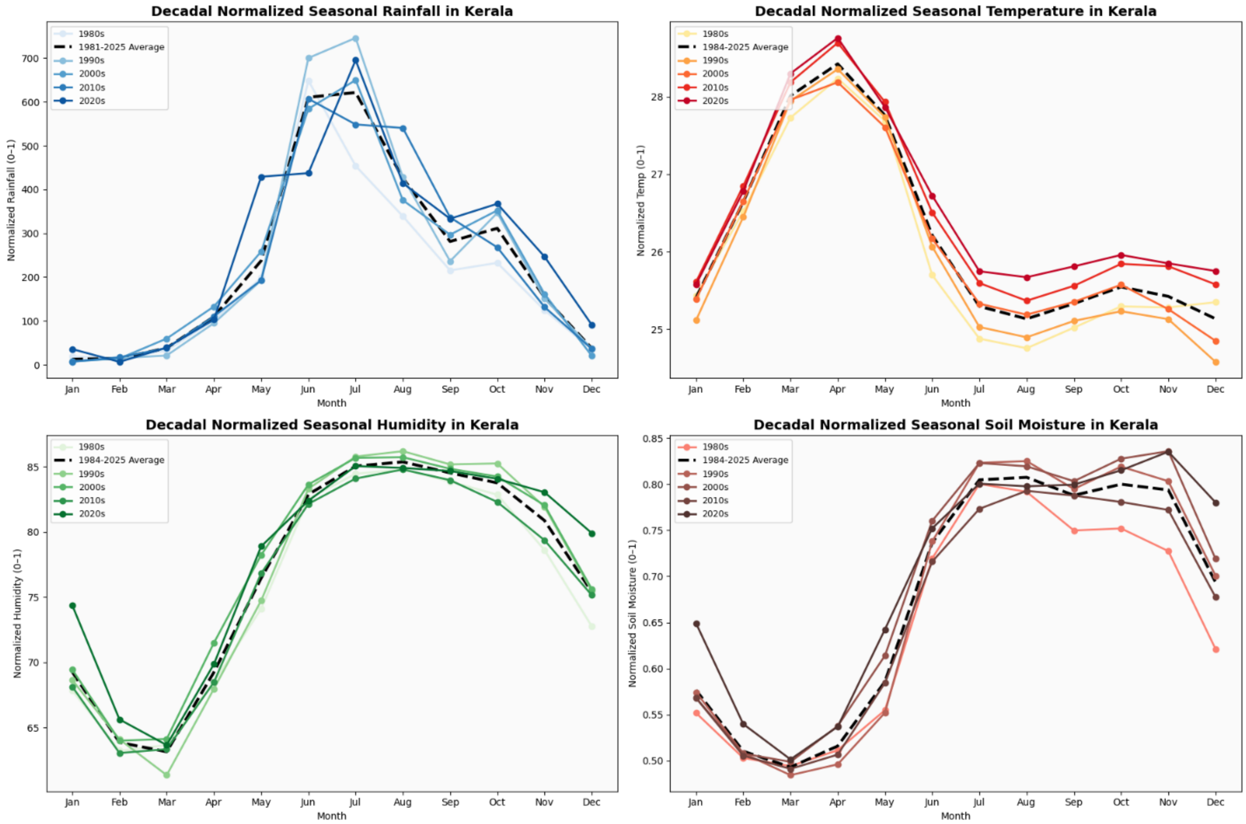

Figure 1: Decadal climate profiles of Kerala showing dispersed rainfall, prolonged soil moisture, and rising pre-monsoon temperatures that intensify crop stress and reinforce yield stagnation.

Evidence from *Agricultural Statistics 2023* highlights two long-term patterns in Kerala's farming sector. Farmers have steadily shifted from staple food crops toward higher-value cash crops. At the same time, yields for several major crops have stagnated or declined since the early 2000s, despite greater use of technology and inputs. While the sector's overall output has remained resilient, this resilience is largely due to higher prices and diversification rather than improvements in land productivity. Year-to-year yield fluctuations have also become sharper, pointing to growing vulnerability.

Complementing these yield patterns, the decadal climate profiles show that rainfall is now more spread out across the year, altering the timing of water availability. Soil moisture levels remain elevated for longer periods during the monsoon, which can increase risks of waterlogging and crop stress. Meanwhile, rising seasonal temperatures, particularly in the pre-monsoon months, are intensifying heat stress during critical crop growth stages. Together, these shifts underline that Kerala's agricultural stagnation is not only structural but also increasingly shaped by changing climate dynamics.

B. Climate Anomaly Impact on Crop Yields

The correlation analysis provided a clear, quantitative link between specific climate anomalies and yield variations, directly validating the urgency outlined in SAPCC 2.0.

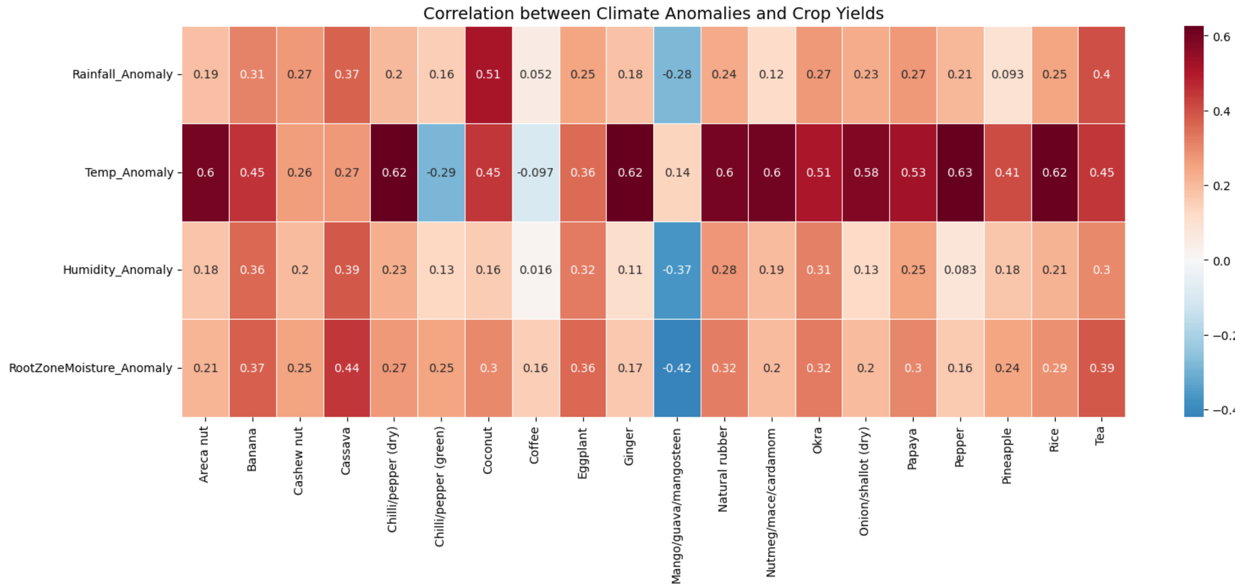

Figure 2: Correlation heatmap showing crops yield sensitivity to rainfall and soil moisture anomalies, with evidence of dual vulnerability to both dry spells and excess wetness.

1. Rainfall and Soil Moisture Sensitivity

The heatmap shows correlation coefficients between crop yields and anomalies in rainfall and root-zone soil moisture. You can see both positive and negative correlations across crops, which supports the claim that yields are sensitive to both **deficits (dry spells)** and **excesses (flooding/waterlogging)**. That aligns with your text about “dual sensitivity to water extremes.”

- **Negative Correlation with Dry Spells:** Crops that rely heavily on monsoon rainfall (e.g., rice, banana) show negative correlations with soil moisture anomalies when moisture is low, which matches the description of drought being a primary yield-reducing factor.
- **Negative Correlation with Extreme Wetness:** Some crops also show negative correlations with high rainfall anomalies, consistent with the idea that excessive rain can damage yields. The heatmap captures this through negative coefficients in the rainfall anomaly rows for certain crops.

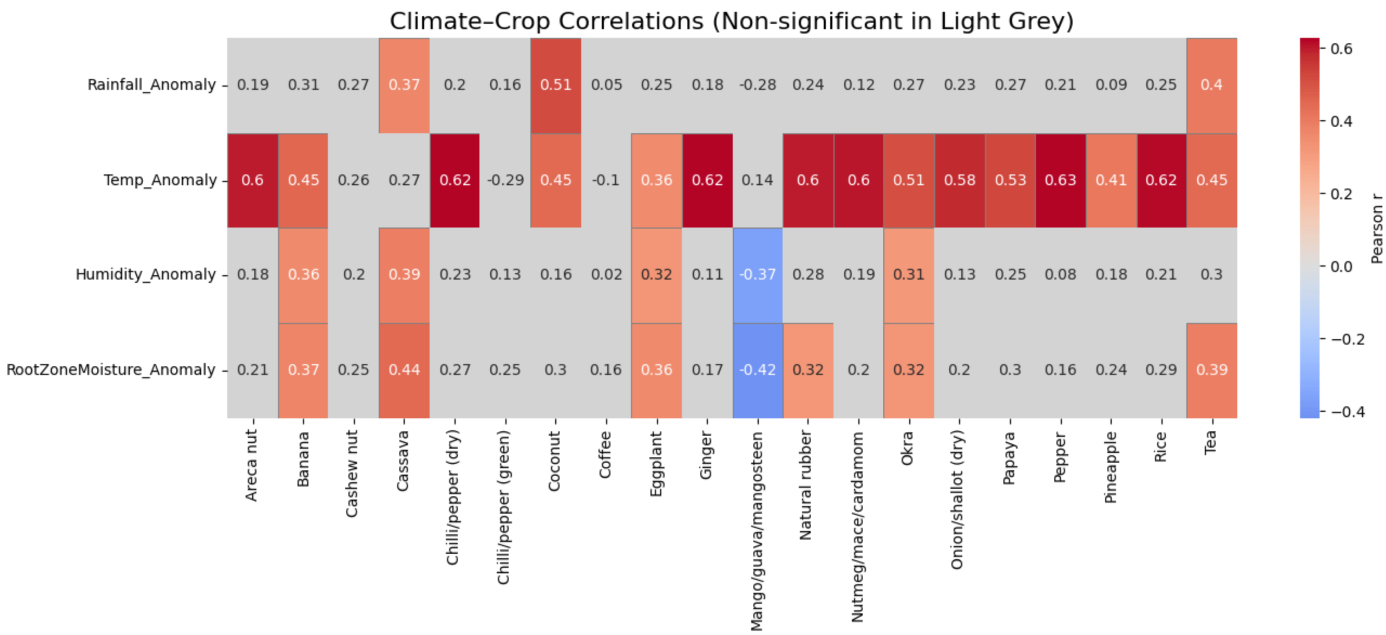

Figure 3: Lagged correlation heatmap revealing that climate anomalies in one season often influence yields in the following season, highlighting delayed but significant impacts on crop performance.

When lagged correlations were introduced, the analysis revealed that the strongest climate-yield relationships often occur with a one-season delay. For example, excess rainfall or soil moisture anomalies in the pre-monsoon period were found to influence yields in the subsequent kharif season. This lag effect highlights that climate shocks do not always translate into immediate yield losses but can carry over into the next cropping cycle, amplifying volatility.

2. Temperature Effects

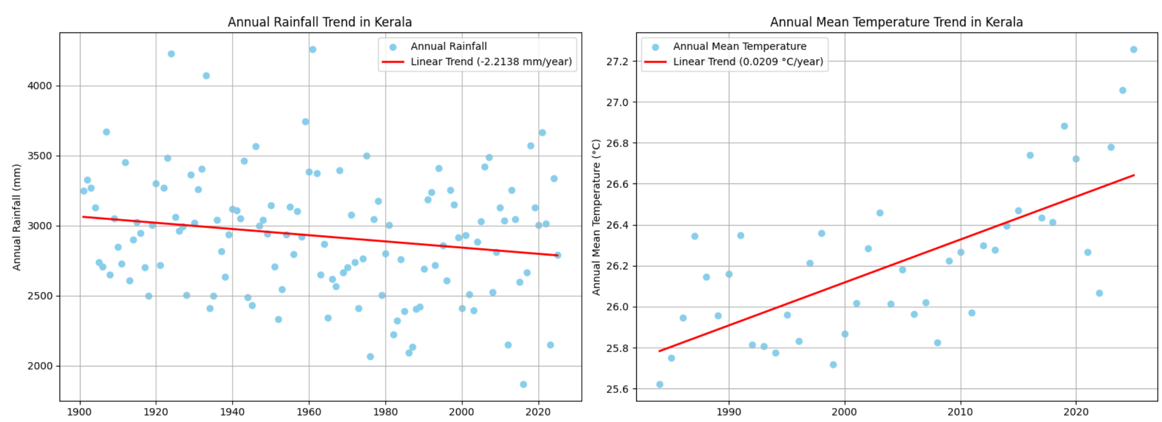

Figure 4: Long-term climate trends in Kerala showing a steady decline in annual rainfall and a simultaneous rise in mean temperature, underscoring the dual pressures of water scarcity and heat stress on agriculture.

Analysis of yield patterns alongside climate records shows that temperature anomalies have a clear and growing influence on crop performance. Heat stress during critical growth stages, particularly flowering and maturation, has been consistently linked to reduced yields for crops such as paddy. The late 1990s to early 2000s marked a turning point, with sensitivity to temperature increases becoming more pronounced. This trend aligns with projections in SAPCC 2.0, which anticipate steadily rising average temperatures across Kerala. The evidence suggests that without adaptive measures, higher temperatures will continue to amplify yield instability and threaten the resilience of key crops.

C. Predictive Modeling and Forecasts

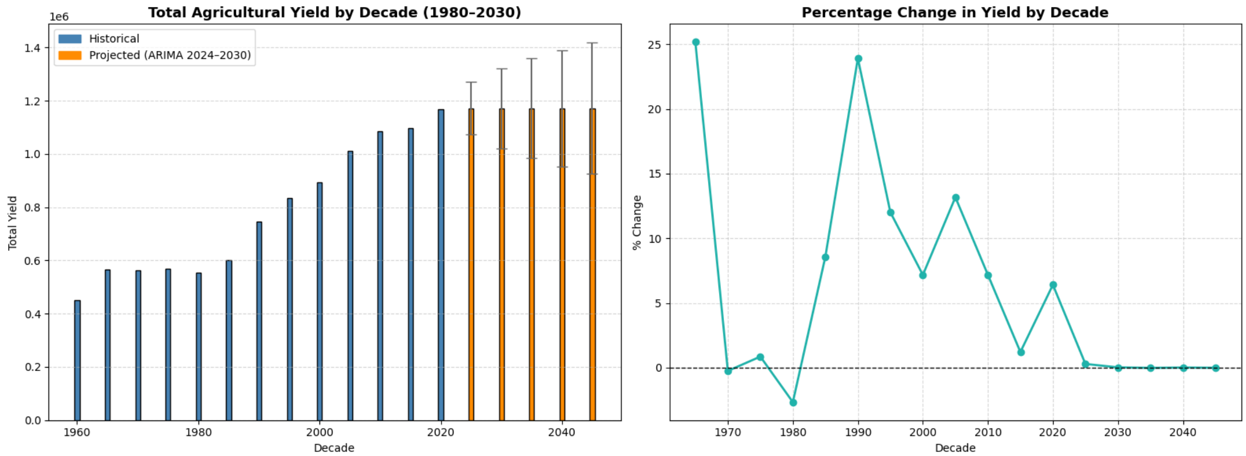

Figure 5: ARIMA-based yield forecasts showing historical trends (bars) and projected trajectories (line), highlighting the limits of purely historical extrapolation in capturing climate-driven volatility.

The time-series forecasting relied on the **ARIMA model**, which was tested with full diagnostics to ensure robustness. Residual checks, autocorrelation plots, and stationarity tests confirmed that the model assumptions were reasonably satisfied.

- **Baseline Forecast:** The ARIMA projections indicated only marginal improvements in future yields, reflecting the inertia of historical stagnation.
- **Climate-Informed Sensitivity:** By testing different break-year thresholds (3%, 5%, 10%), the analysis showed that yield trajectories are highly sensitive to structural shifts and climate variability. These sensitivity checks highlighted that even small changes in climate or management conditions could significantly alter medium-term outcomes.
- **Conclusion of Diagnostics:** The model results reinforce the policy priority outlined in SAPCC 2.0: climate change is already amplifying yield instability, and without adaptive measures, volatility is likely to increase. This underscores the need for climate-smart interventions and better risk management in Kerala's agricultural sector.

V. Discussion

A. The Policy Relevance of Data-Driven Diagnostics

The convergence of the empirical results with the state's official policy confirms the validity and necessity of the *Kerala State Action Plan on Climate Change 2.0*. The SAPCC identifies water resources management and drought proofing as top priorities, which is directly validated by the data showing that yield is most critically sensitive to **soil moisture and rainfall anomalies**, particularly the intensity and duration of dry spells. The data moves the policy discussion from a general concern about climate change to a targeted focus on **water excess and water scarcity management**. For example, the finding of negative correlation with both extreme dry and extreme wet anomalies argues against single-focus strategies (like only building reservoirs) and mandates integrated, landscape-level water management that can absorb both shocks.

B. Resilience: The Myth of Stability

The *Agricultural Statistics 2023* highlighted the sector's resilience in economic terms, but the analysis reveals that this is a fragile stability. The apparent resilience is largely a consequence of structural and market factors such as commodity prices, input subsidies, robust supply chains, and external support, rather than intrinsic ecological or productive strength. Underlying land productivity has stagnated, and the system's sensitivity to climate shocks is increasing. Over the same period, Kerala has also transitioned from being a significant producer of staple crops to increasingly consumer state. Once a surplus producer of rice and other food crops, the state now depends heavily on imports to meet its consumption needs. This dual reality of stagnating productivity at home and rising dependence on external supplies means that a single, severe, and prolonged climate event could quickly collapse the sector's positive economic trajectory, transforming the current resilience into rapid vulnerability. Policy must therefore target the fundamental yield–climate relationship and strengthen local productive capacity, rather than relying solely on market mechanisms.

C. Remittance Linkages and Rural Livelihood Security

A critical policy linkage, not explicitly detailed in the source documents but vital for Kerala's economy, is the relationship between agricultural risk and **international remittances**. Kerala has historically relied heavily on remittances from its diaspora. When agricultural livelihoods fail due to climate-induced shocks, rural families often rely on remittances for immediate recovery and as a long-term strategy for risk mitigation. Over time, recurring climate shocks can trigger a cycle:

1. Climate shock leads to yield failure.
2. Dependence on remittances increases.
3. The next generation may choose outward migration over farming, further accelerating the structural shift away from agriculture and potentially creating a labor shortage for farming.

This analysis suggests that climate change in agriculture acts as a powerful **migration driver**. Effective policy for agricultural resilience is thus also an essential policy for stabilizing rural population dynamics and ensuring the social and economic continuity of local communities. By investing in climate-resilient farming, the state is effectively investing in reducing the need for distress-driven labor migration and strengthening local economies.

VI. Limitations and Assumptions

The analytical study, while robust, operates under several necessary **limitations and assumptions**:

A. Data Constraints and Temporal Scope

The primary limitation stems from the **incomplete temporal data** for both yield and climate variables in the period preceding the 1980s. While interpolation was used, these synthetic data points introduce a degree of uncertainty into the long-term trend analysis. The reliance on publicly available climate data, which often represents regional averages, also limits the ability to draw conclusions for highly localized, micro-climatic effects, a crucial consideration in Kerala's diverse topography.

B. Model-Specific Assumptions

The ARIMA modeling component assumes that the future pattern of yield will be an extrapolation of the past, excluding the influence of external variables. While the more advanced ML models incorporate climate drivers, they are still limited by the fundamental assumption that **historical climate-yield relationships will hold true** in the future. They cannot perfectly predict the emergence of entirely new climate regimes or unforeseen biological responses to extreme multi-stressor events (e.g., simultaneous heat and pest outbreaks).

C. Exclusion of Socio-Political and Technological Factors

The analysis focused primarily on biophysical and climatic drivers. The predictive models **excluded critical socio-political and technological variables** that significantly influence yield outcomes, such as:

- Changes in government subsidy and Minimum Support Price (MSP) policies.
- Adoption rates of new, high-yield or drought-resistant crop varieties.
- Fluctuations in input costs (fertilizer, labor, power).
- Changes in land use and fragmentation policies.

Future research must prioritize incorporating these socio-economic layers to create a truly holistic and policy-actionable predictive framework that addresses the complex reality of farming.

VII. Policy Implications and Recommendations

The synthesis of statistical evidence, policy intent (SAPCC 2.0), and data-driven diagnostics provides clear direction for policy intervention. While water management, localized adaptation, and data infrastructure are critical, the analysis also highlights the importance of **protected cultivation and technology adoption** as cross-cutting levers. The use and adaptation of hydroponics, polyhouses, and other controlled-environment systems can reduce exposure to rainfall variability and heat stress, extend growing seasons, and enable higher-value crop production. These investments complement traditional adaptation measures and should be integrated into Kerala's climate-resilient farming strategy.

A. Prioritize Water Management for Dual Extremes

Implication: The data shows equal vulnerability to water scarcity (droughts) and water excess (flooding).

Recommendation: Move beyond traditional irrigation projects to implement integrated water budget management at the watershed and farm level. This includes:

- **Micro-catchment Rainwater Harvesting:** Promotion of small-scale, decentralized structures to capture and store excess monsoon run-off for use during dry spells, effectively managing both extremes.
- **Precision and Micro-Irrigation:** Accelerated adoption of micro-irrigation systems, coupled with real-time soil moisture monitoring, informed by the data, to minimize water usage and ensure that irrigation is only applied when negative soil moisture anomalies reach critical thresholds.

`B. Implement Hyper-Localized, Data-Informed Adaptation

Implication: General, state-wide adaptation measures are insufficient given the micro-climatic diversity and the localized nature of yield sensitivity.

Recommendation: The SAPCC 2.0's strategy for climate-resilient farming must be operationalized through Panchayat-level climate vulnerability mapping. This requires:

- **Agro-Climatic Zoning based on Anomalies:** Utilizing the analytical framework to classify zones not just by historical climate, but by the projected frequency and intensity of critical climate anomalies (e.g., "High-Risk Heat Stress Zone," "High-Risk Extreme Rainfall Zone").
- **Customized Crop Advisories:** Development of real-time advisories that integrate seasonal climate forecasts with the crop-specific vulnerability findings, guiding farmers on optimal planting and harvesting windows, crop selection, and emergency measures.

C. Investment in Data Infrastructure and Digital Agriculture

Implication: The modeling was limited by historical data gaps and the exclusion of socio-economic factors.

Recommendation: Establish a dedicated Agricultural Climate Data Observatory. This requires a Comprehensive Data Collection mandating uniform, digitized collection of farm-level yield data and land-use changes, integrating with the Department of Agriculture's statistical wing to enhance the reliability of future *Agricultural Statistics* publications.

D. Structural Support for Crop and Income Diversification

Implication: Yield stagnation and increasing volatility make continued reliance on a narrow set of crops financially risky.

Recommendation: Implement structural policies that mitigate risk by supporting crops and income diversification:

- **Promote Climate-Resilient Varieties:** Subsidize research and distribution of short-duration, heat-tolerant, and drought-resistant varieties for staple crops, reducing their sensitivity to critical climate anomalies.

- **Encourage Protected Cultivation and Agro-Investments:** Promote the adoption of hydroponics, polyhouses, and other controlled-environment farming systems. These technologies reduce exposure to rainfall variability and heat stress, extend growing seasons, and enable higher-value crop production, thereby enhancing resilience and farmer incomes.
- **Support Non-Farm Income:** Explicitly design schemes that foster supplementary non-farm income streams (e.g., value addition, agri-tourism, agro-processing) to increase the overall resilience of the rural household, buffering the impact of climate-induced yield failures and reducing reliance on distress migration.

VIII. Conclusion

Kerala's agricultural future is defined by a necessary and inevitable transition. The economic strength and resilience documented in the Agricultural Statistics 2023 provide a crucial window of opportunity, but this window is closing rapidly under the pressure of climate change, as predicted by advanced analytical models. The Kerala State Action Plan on Climate Change 2.0 provides the essential policy vehicle for this transition.

The core finding of this analysis is that the state's agricultural vulnerability is highly specific: it is a sensitivity to anomalies in water availability and temperature at critical points in the crop cycle, rather than a general decline in climate suitability. Moving forward requires policy to be as precise as the data that informs it.

The structural challenge is to translate data-driven insights, such as the quantified risk of yield volatility, into real-world, localized actions that empower farmers. Proactive adaptation, rooted in superior data infrastructure, technological innovation, and integrated water management strategies, will be essential. This includes the wider adoption of protected cultivation systems such as hydroponics and polyhouses, which can buffer climate extremes and enable higher-value, resilient production. By adopting these recommendations, Kerala can ensure that its farming heritage evolves into a resilient, future-ready agricultural system, safeguarding both its ecological integrity and the enduring economic stability of its rural populace.

.IX. References

1. Directorate of Agriculture Development & Farmers' Welfare, Government of Kerala. (*A Compendium of Agricultural Statistics: Kerala 2023*). 2023.
2. Directorate of Environment and Climate Change (DOECC), Government of Kerala. (*Kerala State Action Plan on Climate Change 2.0 (2023-2030*). 2022.
3. Data Sources: Indian Meteorological Department (IMD) for Rainfall
4. NASA Prediction of Worldwide Energy Resources (POWER) for Temperature, Humidity, and Root-Zone Soil Moisture
5. Unified Portal for Agricultural Statistics (UPAg) for historical yield data.