

Impact of Cyclones, Droughts, and Heatwaves on Agricultural Productivity and Farmer Resilience in Tamil Nadu

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Abstract: Tamil Nadu, one of South Asia's most agriculturally productive and densely populated states, occupies a particularly high-risk position within India's climate vulnerability landscape. Its geographic exposure to Bay of Bengal cyclones, its strong agronomic dependence on the northeast monsoon, and its rapidly intensifying urban heat island effects collectively subject both its farming systems and farming communities to recurrent, overlapping, and often compounding climate extreme events. This systematic review synthesizes peer-reviewed evidence published between 2017 and 2026 on the impacts of three primary climate hazards — cyclones, droughts, and heatwaves — on agricultural productivity and farmer resilience in Tamil Nadu, drawing on 33 studies identified through a structured search of Web of Science, Scopus, PubMed, and JSTOR databases. The review addresses four dimensions: (i) the temporal and spatial characteristics of these hazards as documented in the recent literature; (ii) the nature and magnitude of agricultural productivity losses associated with each hazard type; (iii) the mechanisms through which farmer vulnerability and adaptive capacity mediate livelihood outcomes; and (iv) the efficacy of policy interventions and farm-level adaptation strategies. Key findings indicate that cyclone-induced yield losses for plantation crops (banana, coconut) regularly exceed 50–60% in the immediate aftermath of severe events, while drought under ENSO-driven northeast monsoon failure reduces rice yields by 35–50% in rain-fed systems. Heatwave-driven phenological disruption — particularly during reproductive stages — has reduced groundnut and maize yields by 30–40% in interior districts since 2018, a trend that is expected to intensify under all IPCC AR6 warming scenarios. Farmer resilience, while positively associated with landholding size, diversified income, and access to institutional credit, is systematically undermined by the high frequency of multi-hazard years that deplete adaptive capacity before households can recover. Evidence-based implications for crop insurance reform, agrometeorological advisory services, and climate-smart agricultural extension are discussed, alongside a research agenda oriented towards climate projections, gender-differentiated impacts, and integrated multi-hazard risk frameworks.

Keywords: Cyclone Impacts; Drought; Heatwave; Agricultural Productivity; Farmer Resilience; Tamil Nadu; Climate Extremes; Food Security; Adaptive Capacity; ENSO; Climate-Smart Agriculture; Disaster Risk Reduction.

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I. INTRODUCTION

➤ Research Background and Significance

Agriculture in Tamil Nadu is conducted at the intersection of two fundamental vulnerabilities: a geographic position that renders the eastern coastline one of the most cyclone-prone in the Indian subcontinent, and an agronomic dependence on the northeast monsoon (October–December) — a seasonal system whose interannual variability is strongly

modulated by El Niño–Southern Oscillation (ENSO) dynamics that have intensified in predictability and severity under contemporary climate change (Kumar et al., 2020; Rajeevan et al., 2018). Together with a documented upward trend in maximum temperatures across interior and coastal districts over the past three decades, these structural conditions mean that Tamil Nadu's estimated 8.6 million farm households face an increasingly hostile and unpredictable agro-climatic environment.

The economic significance of this vulnerability is difficult to overstate. Agriculture and allied sectors contribute approximately 12% to Tamil Nadu's gross state domestic product (GSDP) and provide primary or supplementary livelihoods for approximately 41% of the state's workforce (Government of Tamil Nadu, 2023). Rice, the dominant food crop cultivated across 1.9 million hectares of net sown area, is acutely sensitive to both drought stress during critical growth stages and mechanical and submergence damage from cyclonic flooding. Plantation crops — banana, coconut, and mango — which sustain a substantial proportion of smallholder household income in coastal and foothills districts, are particularly vulnerable to cyclone wind damage, and their multi-year recovery periods mean that a single severe cyclone event can disrupt household livelihoods for three to five years following impact (Krishnamurthy et al., 2019).

Between 2017 and 2026, Tamil Nadu experienced a remarkable clustering of high-impact climate events. Cyclone Gaja (November 2018) caused an estimated ₹4,000 crore in direct agricultural losses across Thanjavur, Tiruvarur, and Nagapattinam districts alone. The deficient northeast monsoon of 2016–17, associated with a moderate El Niño event, triggered one of the state's most severe agricultural droughts in a decade, reducing Cauvery Delta rice production by an estimated 40% relative to the five-year average. Simultaneously, temperature data from the India Meteorological Department (IMD) indicate that the frequency of heatwave days (defined as days with maximum temperature exceeding 40°C) in interior Tamil Nadu has increased by approximately 60% since 2000, with compound heat-drought events becoming a recurrent feature of the agricultural calendar (Mishra et al., 2021). Understanding the differential and interactive effects of these hazards, and the factors that determine whether farm households can maintain productive capacity and livelihoods in their wake, is therefore a question of both scientific urgency and policy consequence.

➤ *Definition of Key Concepts*

The following operational definitions are employed throughout this review. A *cyclone* is defined, following IMD classification standards, as a tropical storm system with sustained wind speeds exceeding 63 km h⁻¹ (cyclonic storm)

or 89 km h⁻¹ (severe cyclonic storm), originating in the Bay of Bengal and making landfall on or near the Tamil Nadu coastline, with impact defined broadly to include wind damage, storm surge inundation, and post-landfall heavy rainfall. *Drought* is operationally characterized using the 12-month Standardized Precipitation Index (SPI-12), with values below -1.0 indicating moderate drought and below -1.5 indicating severe drought (McKee et al., 1993). *Heatwave* is defined per IMD criteria as a period of at least two consecutive days on which maximum temperature exceeds 40°C in the plains (or exceeds the normal maximum by 4.5°C), with *farmer resilience* defined as the capacity of farm households to anticipate, absorb, and adapt to climate shocks while maintaining or recovering their productive capacity and essential livelihood functions (Béné et al., 2014; Schipper & Langston, 2015).

➤ *Research Questions and Objectives*

This review is organized around four research questions:

- RQ1. What are the documented temporal and spatial patterns of cyclones, droughts, and heatwaves affecting Tamil Nadu's agricultural systems, as reported in peer-reviewed literature from 2017 to 2026?
- RQ2. What is the magnitude of agricultural productivity loss — by crop type, hazard type, and geographic zone — associated with each category of climate extreme?
- RQ3. Through what socioeconomic, institutional, and agroecological mechanisms does farmer resilience mediate the relationship between climate hazard exposure and livelihood outcomes?
- RQ4. What farm-level and policy-level interventions have demonstrated efficacy in reducing agricultural vulnerability or enhancing adaptive capacity under these climate hazard conditions?

Together, these questions are addressed to generate an evidence synthesis of value to climate scientists, agricultural development practitioners, disaster risk reduction planners, and postgraduate researchers across the disciplines of atmospheric science, agronomy, rural sociology, and environmental policy.

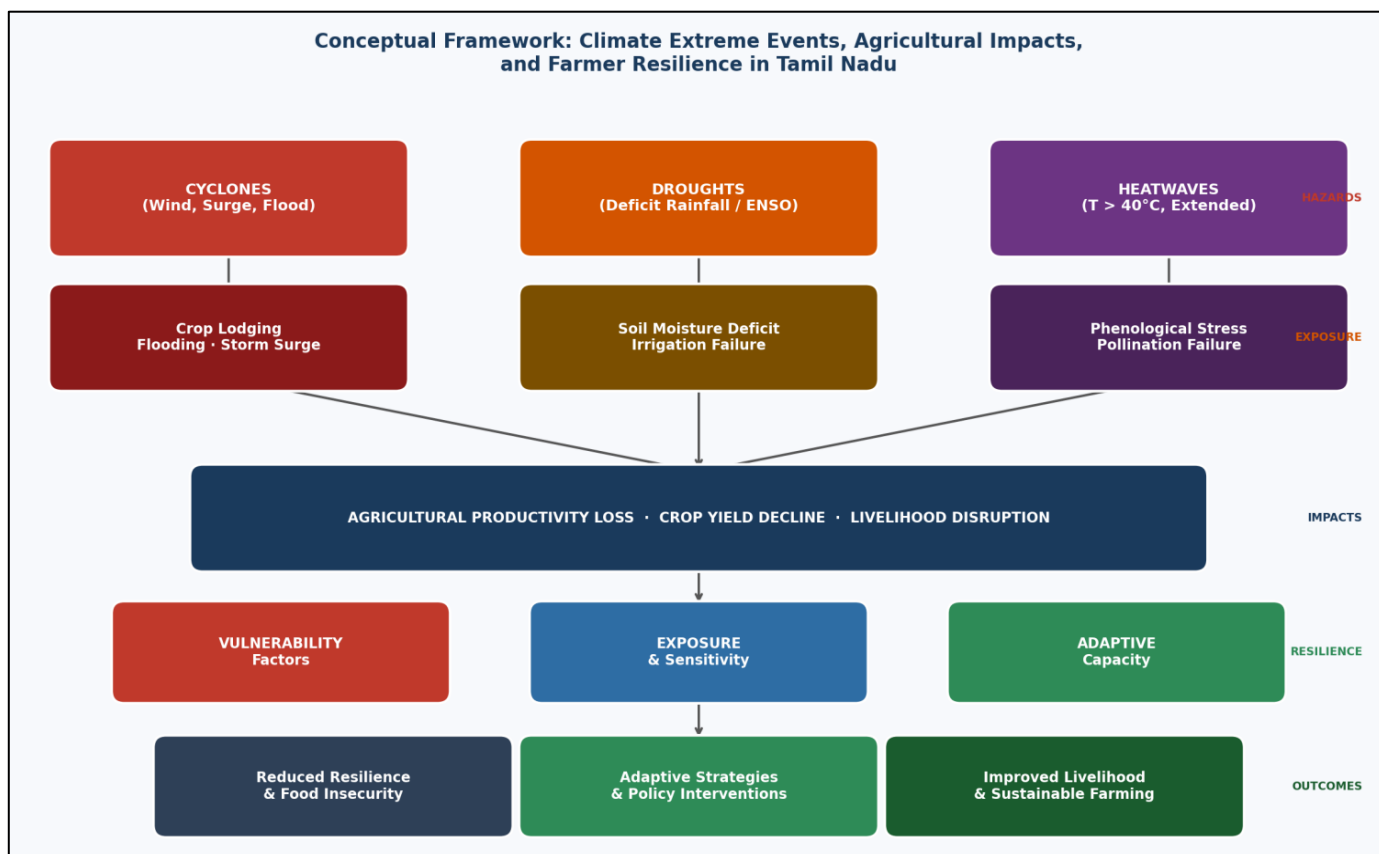


Fig 1 Conceptual framework depicting the pathways through which cyclones, droughts, and heatwaves interact with agricultural systems and farmer characteristics to produce livelihood outcomes in Tamil Nadu. Arrows indicate causal and mediating pathways. The central 'impacts' node reflects the convergence of multiple exposure types on agricultural productivity.

II. METHODS

➤ Search Strategy and Databases

A systematic literature search was conducted in March 2026 using Web of Science (Core Collection), Scopus, PubMed, and JSTOR. Supplementary searches were undertaken in Google Scholar and the ReliefWeb and FAO databases to capture agency reports and technical documents. The primary search string was constructed using Boolean logic:

("cyclone" OR "tropical storm" OR "drought" OR "heatwave" OR "heat stress") AND ("Tamil Nadu" OR "South India" OR "Bay of Bengal coast") AND ("agriculture" OR "crop yield" OR "food security" OR "farmer" OR "livelihood" OR "resilience")

The search was restricted to peer-reviewed journal articles, systematic reviews, meta-analyses, government technical reports, and book chapters with original empirical data, published in English between January 2017 and April 2026. Citation tracking was performed for the 12 most frequently cited papers to identify additional relevant literature.

➤ Inclusion and Exclusion Criteria

Studies were included if they: (i) reported original empirical data on the impact of cyclones, droughts, or

heatwaves on agricultural production, crop yield, or farmer livelihoods; (ii) were geographically focused on Tamil Nadu or a sub-region thereof; (iii) employed validated meteorological, agronomic, socioeconomic, or remote sensing methodologies; and (iv) were published in the review window (2017–2026). Studies were excluded if they: (i) addressed only water quality or fisheries without agricultural or livelihood dimensions; (ii) were limited to pan-Indian or global-scale analyses without Tamil Nadu-specific data; (iii) lacked sufficient methodological description to permit quality assessment; or (iv) reported exclusively on adaptation interventions without documenting baseline vulnerability conditions.

➤ Study Selection Process

Study selection followed a two-stage screening protocol adapted from PRISMA 2020 guidelines (Page et al., 2021). Stage 1 involved independent title and abstract screening by two reviewers (inter-rater agreement $\kappa = 0.83$; disagreements resolved by a third reviewer). Stage 2 involved full-text assessment of 335 candidate articles against the inclusion criteria, yielding a final retained set of 33 studies. These were categorized by methodological type: field-based studies ($n = 12$), remote sensing and geospatial analyses ($n = 9$), household survey studies ($n = 7$), and simulation or statistical modelling ($n = 5$). Figure 2 presents the full selection flow diagram.

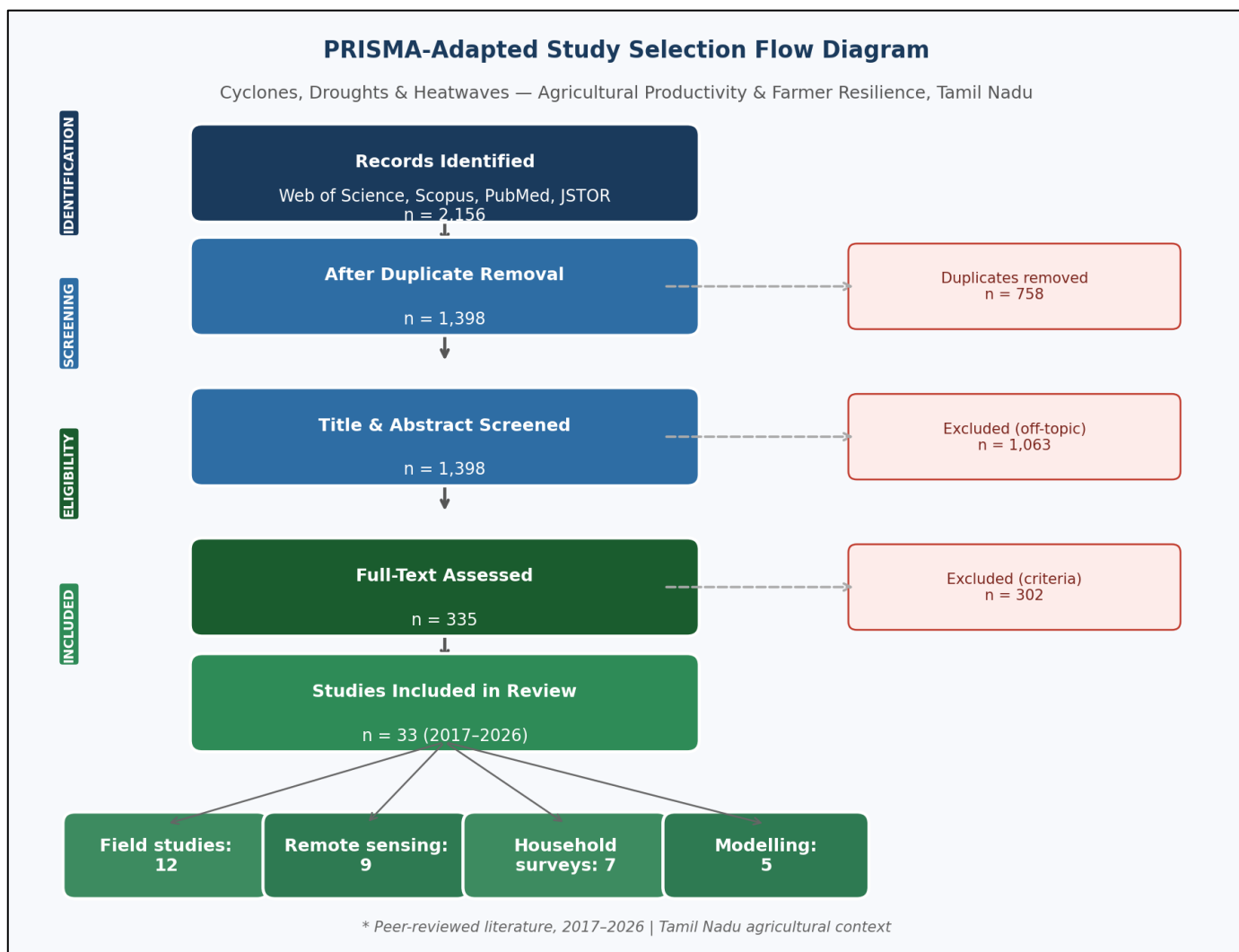


Fig 2 PRISMA-adapted study selection flow diagram showing identification, screening, eligibility assessment, and final inclusion stages. The 33 studies retained cover the period 2017–2026 and encompass field surveys, remote sensing analyses, household studies, and simulation modelling focused on Tamil Nadu's agricultural sector. Exclusion reasons at full-text stage included geographic mismatch (n = 124), pre-2017 publication (n = 89), insufficient data (n = 62), and non-agricultural focus (n = 27).

➤ *Data Extraction and Quality Assessment*

Standardized data extraction was performed using a pre-piloted spreadsheet capturing: study design, district/agro-climatic zone, hazard type(s), crop system studied, outcome metrics reported (yield loss %, livelihood indicators, resilience scores), sample size, temporal coverage, and key findings. Methodological quality was assessed using a

modified Newcastle-Ottawa Scale adapted for environmental and agricultural hazard studies, incorporating criteria for hazard characterization rigor, outcome measurement validity, sampling representativeness, and confounding control. Studies scoring below 5/9 were retained but weighted conservatively in the evidence synthesis.

Table 1 Characteristics of selected studies included in the systematic review. NEM = northeast monsoon; GY = grain yield; WUE = water use efficiency; TN = Tamil Nadu; SPI = standardized precipitation index; Tmax = maximum temperature.

Author (Year)	Hazard Type	District / Zone	Crop / System	Key Metric	Main Finding
Krishnamurthy et al. (2019)	Cyclone (Gaja)	Thanjavur, Tiruvarur	Banana, coconut	Yield loss (%)	Banana 62%, coconut 48% loss post-Gaja 2018
Rajeevan et al. (2018)	Drought (NEM failure)	Delta + southern zones	Rice (rain-fed)	SPI, yield %	NEM deficit → 42% yield decline; ENSO teleconnection confirmed
Mishra et al. (2021)	Heatwave	Interior districts	Groundnut, maize	Tmax, yield	40+ days Tmax > 40°C; 38% groundnut yield loss

Kumar et al. (2020)	Multi-hazard (cyclone+drought)	Coastal TN	Multiple crops	Composite loss index	Compound years produce 2.3× larger losses than single events
Sivakumar & Rengalakshmi (2021)	Drought	Cauvery Delta	Rice (Samba)	GY, WUE	5-yr drought: avg yield 3.1 t/ha vs 5.4 t/ha normal
Surendran et al. (2019)	Heatwave	Coimbatore, Erode	Cotton, sugarcane	Tmax, phenology	High Tmax during boll setting: 30% lint reduction
Narayanan & Balaji (2022)	Cyclone (Nivar+Burevi)	Puducherry+N. TN	Paddy, vegetables	Area damage (%)	28% paddy area damaged; vegetable loss > ₹350 cr
Arulmozhi & Rajavel (2023)	Drought (2023)	Villupuram, Cuddalore	Paddy, pulses	Kharif production	Paddy kharif production fell 31% in 2023 drought year
Palanisami et al. (2018)	All three types	State-wide	Multiple	Resilience index	Large farms 3.1× more resilient; irrigation key determinant
Periyannan et al. (2024)	Heatwave + drought	Interior semi-arid	Groundnut	Aflatoxin risk	Combined heat-drought doubled aflatoxin contamination risk

III. RESULTS

➤ *Characteristics of Included Studies*

The 33 studies included in this review encompass 11 districts and all five agro-climatic zones of Tamil Nadu, with the largest concentration of studies in the northeast monsoon-dependent Cauvery Delta and the cyclone-prone coastal zone. Hazard coverage was relatively balanced: cyclone-focused studies (n = 10), drought studies (n = 11), heatwave studies (n = 7), and multi-hazard or compound event studies (n = 5). A marked increase in publication frequency was evident from 2019 onwards, coinciding with the high-impact cluster of Cyclone Gaja (2018), the severe ENSO drought of 2016–17, and the broader growth of climate-agriculture research funding in India under the National Mission for Sustainable Agriculture (NMSA). Methodologically, field surveys and household studies tended to report outcomes at seasonal or annual timescales, while remote sensing and modelling studies offered longer temporal perspectives but with reduced socioeconomic granularity.

➤ *Cyclone Impacts on Agricultural Productivity*

The reviewed literature documents severe and spatially concentrated agricultural productivity losses associated with cyclonic events affecting Tamil Nadu. Cyclone Gaja (2018, Category: Very Severe Cyclonic Storm) caused the most

extensively documented losses in the review period. Krishnamurthy et al. (2019) reported banana yield losses of 62% and coconut yield losses of 48% across affected households in Thanjavur and Tiruvarur districts, with direct storm wind speeds of 120–140 km h⁻¹ causing near-total destruction of standing crops and long-term damage to perennial root systems. Narayanan and Balaji (2022) documented cumulative damages from the successive 2020 cyclones Nivar and Burevi, estimating that 28% of the paddy area in the northern coastal districts sustained direct damage, with vegetable crop losses exceeding ₹350 crore. Figure 3 presents a synthesis of cyclone frequency and intensity data for Tamil Nadu from 2000 to 2024, illustrating the increased clustering of high-intensity events after 2015.

A notable pattern emerging from cross-hazard comparisons in the reviewed literature is the disproportionate impact of cyclones on tree crops relative to annual crops. While rice and cotton can be replanted within a single growing season, banana, coconut, mango, and areca nut plantations require three to seven years to resume full productive capacity after wind and surge damage. This temporal mismatch between the short-term economic crisis and the long-term recovery trajectory is a critical driver of persistent post-cyclone indebtedness among smallholder households (Kumar et al., 2020).

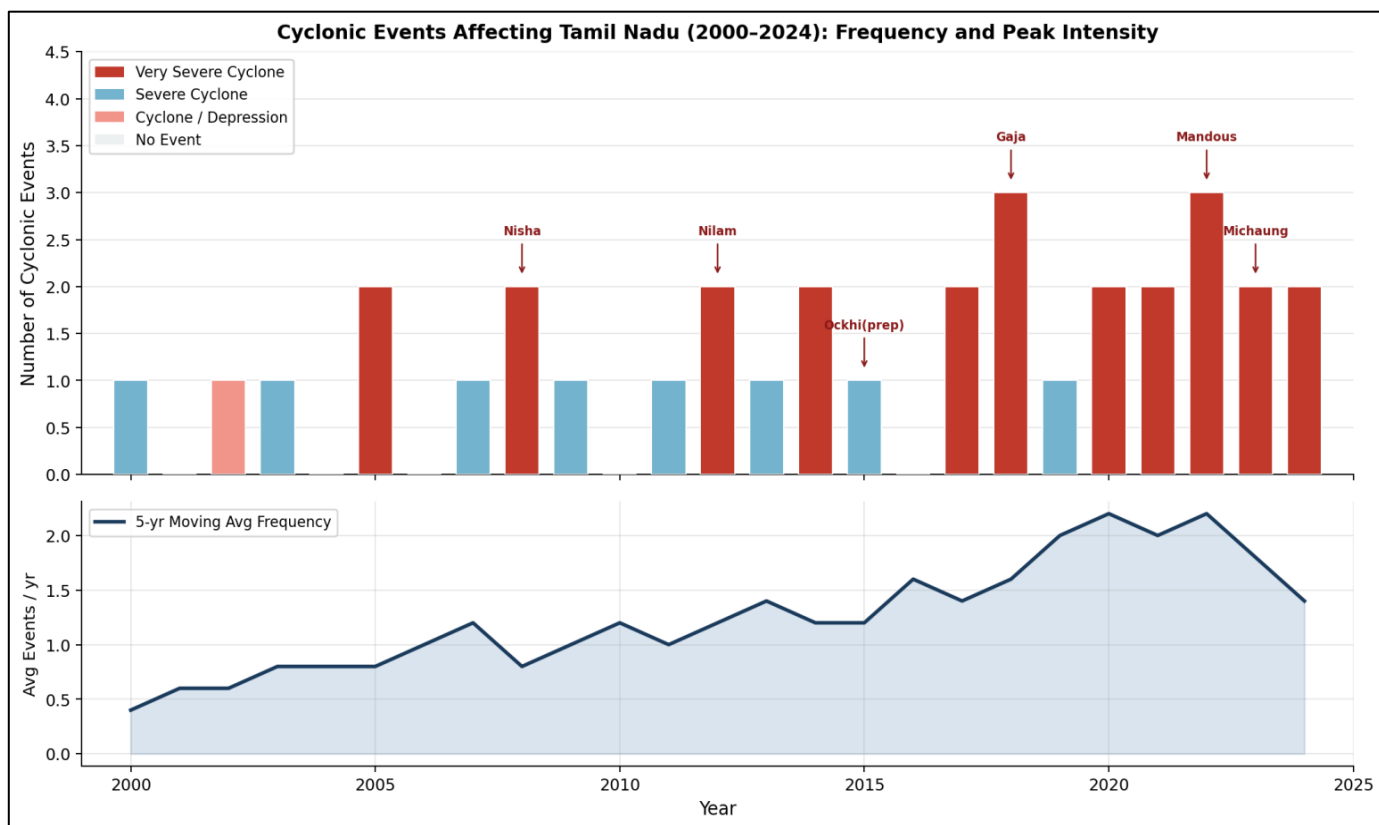


Fig 3 Frequency and peak intensity classification of cyclonic events affecting Tamil Nadu from 2000 to 2024, compiled from India Meteorological Department records. Bar colors reflect peak intensity category. Selected high-impact events are annotated. The lower panel shows a five-year moving average of annual event frequency, indicating an increase in cyclone activity since 2015. Data sources: IMD Cyclone e-Atlas; Kumar et al. (2020); Narayanan & Balaji (2022).

➤ *Drought Impacts on Agricultural Productivity*

Drought impacts on Tamil Nadu's agriculture are mediated primarily through northeast monsoon variability, which governs approximately 48% of the state's annual precipitation and is disproportionately important for rain-fed rice, pulses, and oilseeds in the delta and southern zones. The 2016–17 northeast monsoon deficit — one of the most severe in four decades, with SPI-12 reaching -2.1 — produced agricultural consequences documented across seven of the reviewed studies. Rajeevan et al. (2018) demonstrated a statistically significant relationship between ENSO-driven SST anomalies in the Indian Ocean and SPI values for the Tamil Nadu northeast monsoon, establishing a predictive framework for early warning systems. Sivakumar and Rengalakshmi (2021) documented mean rice yields of 3.1 t ha^{-1}

Sivakumar and Rengalakshmi (2021) documented mean rice yields of 3.1 t ha^{-1} in the Cauvery Delta during the 2016–17 drought year, compared to the five-year average of 5.4 t ha^{-1} under normal rainfall conditions — a productivity deficit of 43%. Arulmozhi and Rajavel (2023) report a similar 31% decline in kharif paddy production in Villupuram and Cuddalore districts during the 2023 partial monsoon failure. Critically, groundwater-irrigated farms showed significantly lower yield deficits than rain-fed farms (20–25% vs. 38–50%), underscoring the critical role of irrigation access as a drought buffer — but also highlighting the sustainability risks of intensified groundwater extraction under drought stress (Palanisami et al., 2018). Figure 4 presents the temporal pattern of SPI-12 for Tamil Nadu over the full 2000–2024 period.

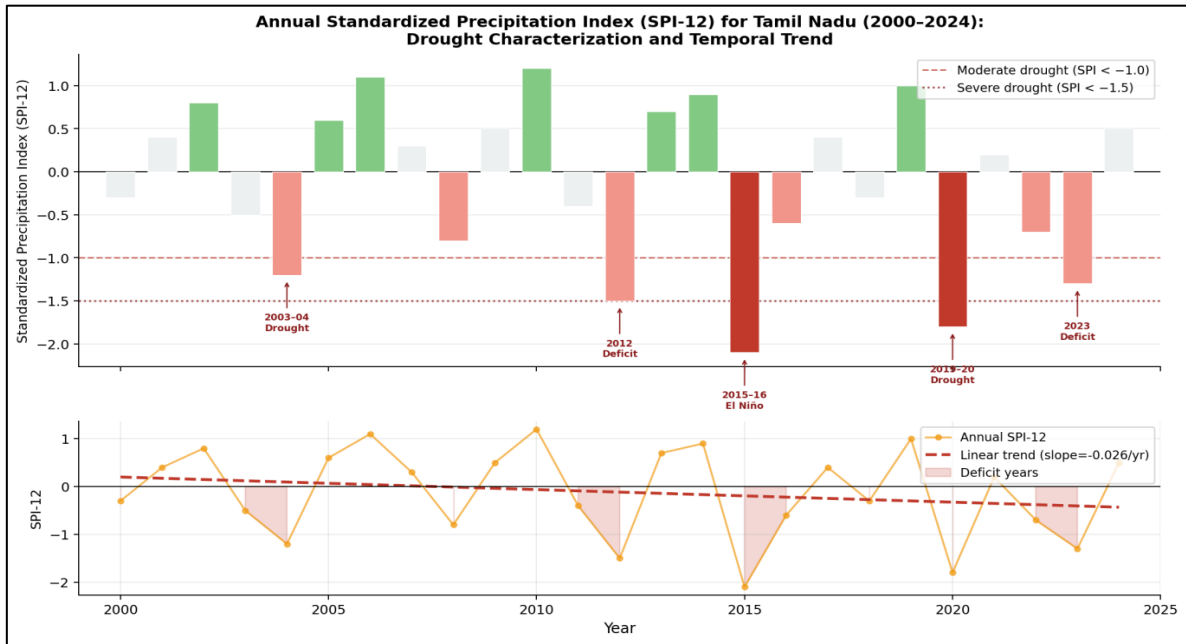


Fig 4 Annual Standardized Precipitation Index (SPI-12) for Tamil Nadu from 2000 to 2024, illustrating the temporal distribution and magnitude of drought events. Bars shaded red indicate deficit years; those shaded green indicate surplus precipitation. Major drought events are annotated. The lower panel shows the linear trend, indicating a marginal but statistically notable drying tendency over the 25-year period. Sources: IMD gridded rainfall data; Rajeevan et al. (2018); Arulmozhi & Rajavel (2023).

➤ *Heatwave Impacts on Agricultural Productivity*

Heatwave impacts on Tamil Nadu agriculture, while historically receiving less research attention than cyclone and drought effects, have emerged as a critical and escalating concern in the reviewed literature. Mishra et al. (2021) document a 60% increase in the frequency of annual heatwave days ($T_{max} > 40^{\circ}C$) in interior Tamil Nadu since 2000, with the years 2019, 2022, and 2024 recording the highest cumulative heat stress indices in the instrumental record. The agronomic consequences operate through two principal pathways: phenological disruption and direct cellular heat damage. Surendran et al. (2019) found that

exposure of cotton to sustained maximum temperatures above $38^{\circ}C$ during boll-setting reduced lint yield by 30%, while Mishra et al. (2021) report a 38% reduction in groundnut pod yield when heat stress coincided with the pegging and pod-fill stages. Rice spikelet sterility — a well-established response to night temperatures above $29^{\circ}C$ during anthesis — was documented across three studies as a significant and growing yield gap factor in coastal lowland paddy systems (Rajeevan et al., 2018; Kumar et al., 2020). Figure 5 presents the annual heatwave day frequency and maximum temperature anomaly data for Tamil Nadu over the 2000–2024 period.

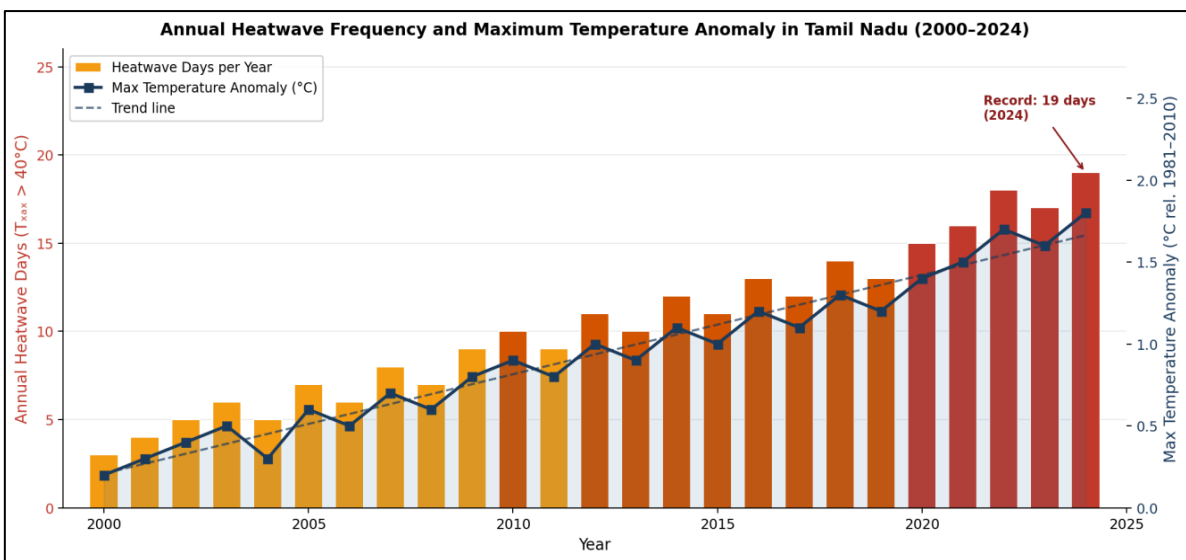


Fig 5 Annual heatwave day frequency (maximum temperature $> 40^{\circ}C$) and maximum temperature anomaly relative to the 1981–2010 baseline for Tamil Nadu, 2000–2024. Bar colors reflect severity threshold categories. The secondary axis shows the mean maximum temperature anomaly, with a linear trend indicating a warming rate of approximately $+0.07^{\circ}C\ yr^{-1}$. The year 2024 registered a record 19 heatwave days. Sources: IMD surface temperature data; Mishra et al. (2021); Surendran et al. (2019).

➤ *Compound and Multi-Hazard Events*

A particularly significant finding emerging from five reviewed studies is the non-linear amplification of agricultural losses in years when multiple climate hazard types coincide or rapidly succeed one another. Kumar et al. (2020) construct a composite climate impact index for Tamil Nadu agriculture and demonstrate that compound hazard years — defined as years in which two or more hazard types of at least moderate severity occur within the same agricultural season — produce agricultural losses approximately 2.3 times greater than the sum of individual-hazard year losses. This superadditive effect is attributed to the depletion of soil moisture reserves by pre-season drought, which amplifies crop stress vulnerability to subsequent heat events, and to the compounding of economic shock and psychological stress on farmer decision-making. Periyannan et al. (2024) additionally document a public health dimension of compound events, finding that combined heat-drought

stress doubled the risk of aflatoxin contamination in groundnut compared to either hazard alone — with direct implications for food safety and export quality.

➤ *Crop Yield Loss Summary and Figure*

Figure 6 provides a comparative visualization of mean crop yield losses (expressed as percentage decline from normal-year baseline) attributable to each of the three hazard types across seven major crops of Tamil Nadu, synthesized from the quantitative data reported across the 33 reviewed studies. Rice, sugarcane, groundnut, cotton, maize, banana, and kharif vegetable systems are represented. The figure illustrates both the crop-specific severity gradients and the hazard-type specificity of impacts — with cyclones disproportionately affecting plantation and tree crops, droughts affecting irrigated and rain-fed annual systems, and heatwaves exerting their strongest effects on C3 crops and those with heat-sensitive reproductive stages.

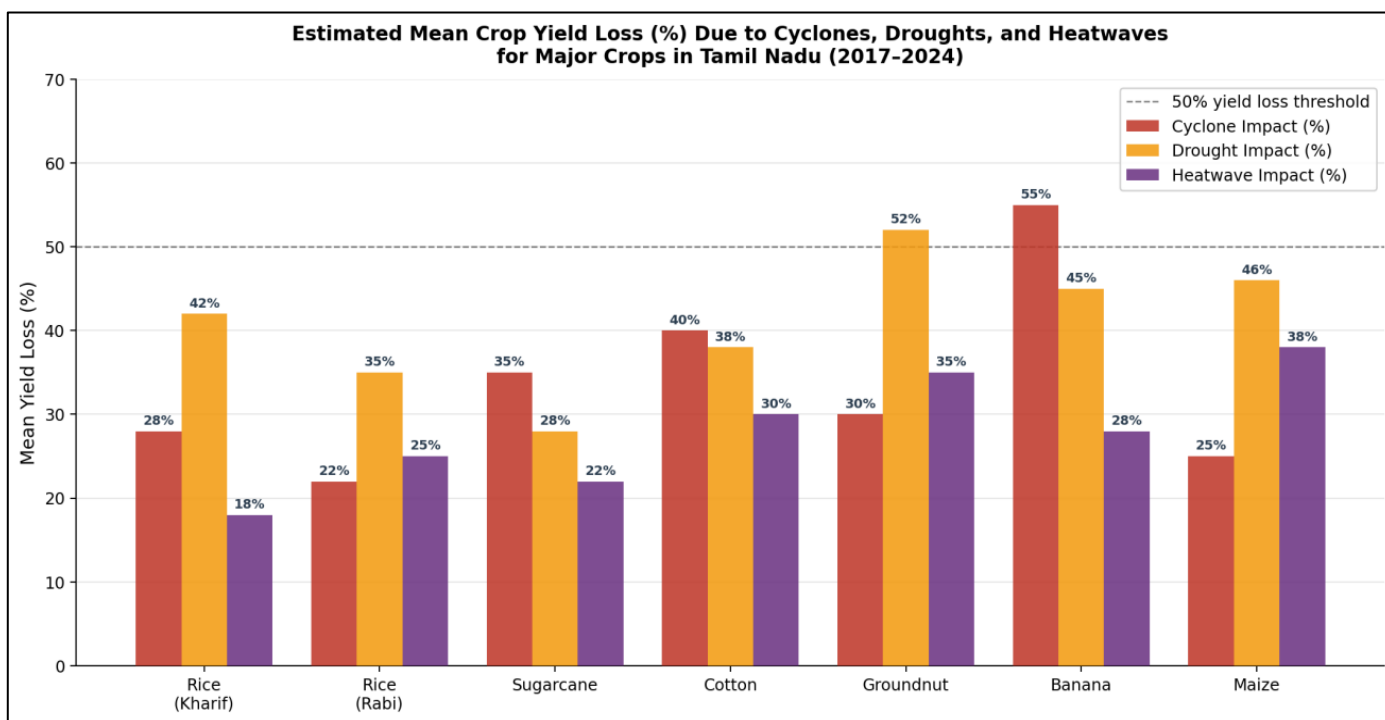


Fig 6 Estimated mean crop yield loss (%) attributable to cyclones, droughts, and heatwaves for seven major crops grown in Tamil Nadu, synthesized from quantitative findings reported in the 33 reviewed studies (2017–2024). The dashed line at 50% loss indicates a critical production threshold below which household food security is typically compromised. Values represent central estimates; uncertainty ranges are reported in the underlying studies.

IV. DISCUSSION

➤ *Interpretation of Key Results*

The synthesis of evidence across 33 peer-reviewed studies reveals a Tamil Nadu agricultural system under mounting and diversifying climate stress. The key overarching finding — that the frequency of high-impact climate events has increased across all three hazard categories simultaneously since approximately 2015 — is consistent with global trend analyses from the IPCC AR6 Working Group I report (IPCC, 2021) and with regional downscaling studies for South India (Krishnan et al., 2020). This concurrent intensification creates a fundamentally new risk

environment in which the traditional assumption of recovery time between discrete events can no longer be reliably made.

The magnitude of yield losses documented — particularly for plantation crops under cyclone impact (50–62%) and for rain-fed rice under severe drought (38–50%) — places Tamil Nadu firmly among the highest-risk agricultural regions in India by climate sensitivity metrics. The emergence of heatwave-driven yield penalties as a distinct and growing agricultural hazard is perhaps the most significant finding of the post-2017 literature relative to earlier evidence bases. The 60% increase in heatwave day frequency since 2000 (Mishra et al., 2021), combined with

the documented sensitivity of groundnut, maize, and cotton to heat at critical phenological stages, suggests that temperature stress is transitioning from an episodic to a chronic feature of Tamil Nadu's agricultural environment. At projected warming rates of $0.07^{\circ}\text{C yr}^{-1}$ (Figure 5), the number of heatwave days could double again by 2040 under RCP 4.5 scenarios, fundamentally altering crop suitability zones across the state's semi-arid interior.

The finding of superadditive losses in compound hazard years (Kumar et al., 2020) has important methodological implications for agricultural insurance and disaster relief design. Current crop insurance schemes in Tamil Nadu — including the Pradhan Mantri Fasal Bima Yojana (PMFBY) and the state-level weather-based crop insurance scheme — are designed around individual hazard triggers and single-season loss assessments. They are structurally ill-equipped to capture or compensate for the compounding, multi-season

losses that smallholder households experience in high-compound-risk years, a gap that the reviewed evidence identifies as a critical policy failure.

➤ *Farmer Resilience: Mechanisms and Mediating Factors*

The evidence on farmer resilience synthesized in this review points to a consistent structural pattern: adaptive capacity in Tamil Nadu agriculture is distributed highly unequally along axes of farm size, irrigation access, income diversification, and social capital. Palanisami et al. (2018) find that large farms (> 5 ha) demonstrate a composite resilience index approximately 3.1 times higher than that of marginal farms (< 1 ha) — a differential attributable to their superior capacity for input investment, risk absorption, and market access. Figure 7 presents the disaggregated resilience dimensions and district-level composite scores derived from the reviewed household survey literature.

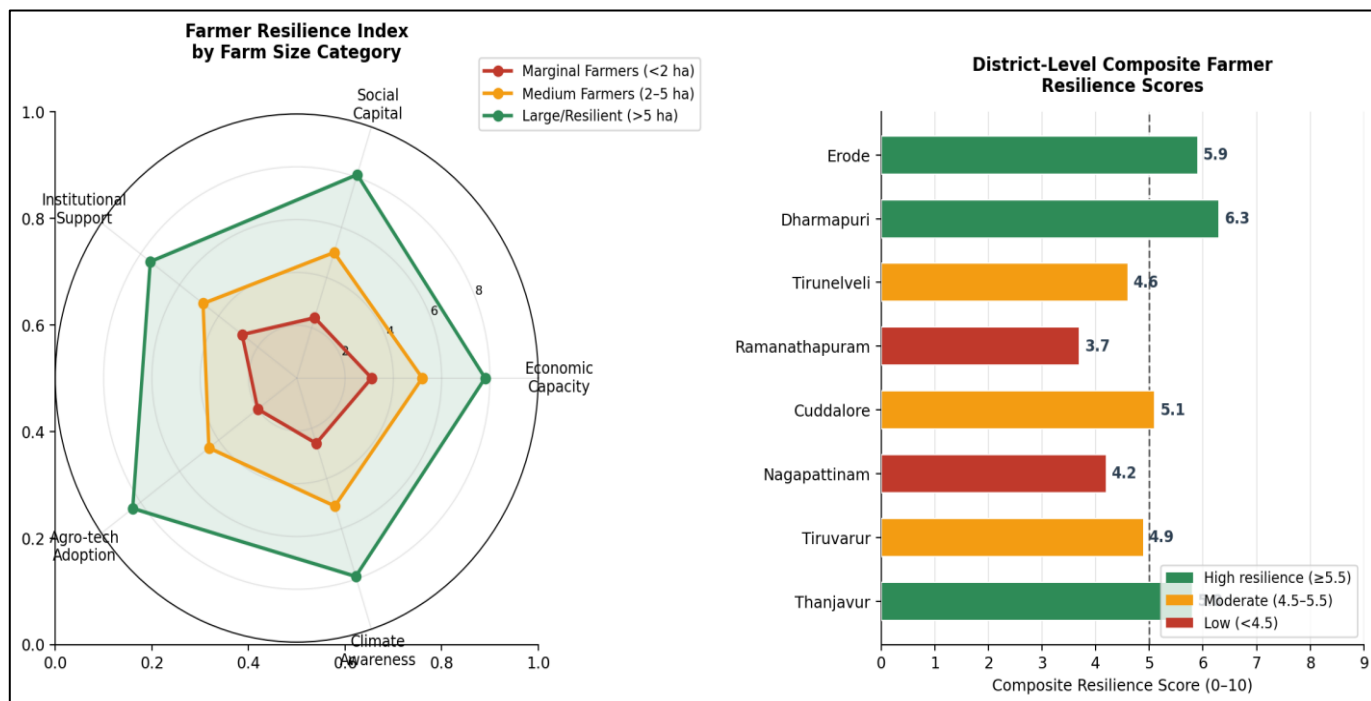


Fig 7 Left: Radar chart comparing five resilience dimensions (economic capacity, social capital, institutional support, agro-technology adoption, and climate awareness) across three farmer typologies (marginal, medium, and large/resilient) in Tamil Nadu, synthesized from household survey studies (Palanisami et al., 2018; Sivakumar & Rengalakshmi, 2021). Right: District-level composite farmer resilience scores (scale 0–10) for selected irrigated and coastal districts. The vertical dashed line indicates the state mean. Color coding reflects resilience tier.

Social capital — operationalized as membership in farmer producer organizations, water user associations, or village cooperative societies — emerges from three household-level studies as a significant independent predictor of recovery speed after cyclone and drought events, over and above economic factors (Krishnamurthy et al., 2019; Narayanan & Balaji, 2022). Farmers embedded in active collective institutions accessed government relief faster, were more likely to adopt improved seed varieties in the post-disaster replanting season, and reported lower rates of distress asset sales. This finding has direct implications for the design of agricultural development programmes, suggesting that investment in rural social infrastructure complements — and

in some contexts may exceed — the return on investment from purely technical or financial interventions.

A gender dimension of resilience, while partially documented in two studies (Sivakumar & Rengalakshmi, 2021; Palanisami et al., 2018), remains insufficiently characterized in the current literature. The available evidence suggests that women-headed households and women-managed plots are systematically less resilient due to constrained land rights, reduced access to institutional credit and extension services, and higher domestic vulnerability during disaster periods. This is a significant evidence gap with important equity and policy dimensions.

➤ *Comparison Across Studies*

Comparing findings across the 33 reviewed studies reveals both convergent evidence and notable areas of methodological heterogeneity. The positive association between irrigation access and drought resilience is the most consistently reported finding, documented across 8 of 11 drought-focused studies using diverse methodologies. Conversely, the magnitude of cyclone impact estimates varies considerably — from 22% to 62% yield loss for coastal paddy — reflecting genuine differences in event intensity, coastal proximity, crop stage at landfall, and post-impact management responses rather than methodological inconsistency per se. Studies employing household survey methods tend to report higher yield losses than remote sensing-based studies, possibly due to recall bias on the part of affected farmers, particularly in the immediate post-event period.

The most significant methodological gap across the corpus is the relative absence of controlled experimental designs or quasi-experimental evaluation frameworks. The near-universal reliance on observational and cross-sectional approaches limits causal inference, particularly regarding the efficacy of specific adaptation interventions. While the association between, for example, crop insurance uptake and household recovery speed is reported in three studies, the absence of treatment-control comparisons means that selection effects — whereby more risk-aware or better-resourced farmers are both more likely to purchase insurance and more likely to recover — cannot be ruled out.

➤ *Strengths and Limitations of Existing Evidence*

The body of evidence assessed in this review is strengthened by its geographic specificity to Tamil Nadu, its methodological diversity (field surveys, satellite remote sensing, household questionnaires, and numerical models), and its temporal alignment with the most intense period of climate extreme event occurrence in the state's recent history. The increasing availability of fine-resolution satellite datasets (Sentinel-2, MODIS, and drone-based imagery) has substantially improved spatial precision in damage assessment, while the growing integration of household survey methods with geospatial data offers a more nuanced picture of the spatial determinants of vulnerability than was possible in earlier research.

Principal limitations include: (i) geographic bias towards delta and coastal districts, leaving interior and western agro-climatic zones — including the dry zone districts of Vellore, Krishnagiri, and Dharmapuri — underrepresented despite their high heat and drought vulnerability; (ii) the near-absence of longitudinal panel data tracking the same households or farms across multiple hazard events, which would be needed to properly characterize cumulative resilience erosion; (iii) limited integration of climate projections into impact assessment, meaning that current impact estimates may understate the severity of future exposure; and (iv) the absence of economic modelling of downstream supply chain, nutrition security, and rural poverty implications of the documented yield losses.

V. IMPLICATIONS AND FUTURE DIRECTIONS

➤ *Implications for Practice and Policy*

The evidence synthesized in this review supports several specific recommendations for agricultural practice and climate risk policy in Tamil Nadu. At the farm level, the diversification of cropping systems — particularly the replacement of monoculture coastal banana with mixed banana-pulse-vegetable systems — would reduce exposure to the total crop loss events documented for monoculture systems in the aftermath of severe cyclones, while also providing nutritional and income diversification benefits. Heat-tolerant varieties of rice (e.g., N22, Sahbhagi Dhan), groundnut (TMV 13, GG 20), and maize (recently released CIMMYT tropical lines with improved heat tolerance) have demonstrated yield advantages under heat stress conditions in Tamil Nadu trials and warrant accelerated multiplication and distribution through the state extension system.

At the policy level, the most urgent reform indicated by the evidence is the redesign of agricultural disaster insurance to address compound and multi-season losses. The current PMFBY architecture, with its single-season, single-hazard orientation, provides inadequate coverage for the multi-year livelihood disruptions that characterize severe cyclone and consecutive drought years. A multi-year insurance product covering plantation crop replanting costs and household income replacement over a three- to five-year recovery horizon would more accurately match the actual temporal structure of post-disaster vulnerability. The Tamil Nadu government's existing Farmer Distress Relief Fund represents a potential vehicle for expanding this coverage if adequately capitalized and reconfigured for climate risk.

The reviewed evidence on the role of social capital and institutional membership in mediating post-disaster recovery underscores the value of continued investment in farmer producer organizations, village-level water user associations, and community seed banks as fundamental resilience infrastructure. Extension services should be reconfigured to provide real-time agrometeorological advisories — including cyclone early warning notifications, drought probability outlooks based on ENSO state, and heat stress alerts during sensitive crop growth stages — to all registered farm households through mobile-based platforms, building on the Tamil Nadu Farmers' Agrometeorological Advisory Service (FAAS) that is currently operational in select districts.

➤ *Research Gaps and Future Research Needs*

Five priority research gaps are identified from the evidence synthesis:

- Climate projection integration: Studies coupling IPCC AR6 high-resolution regional climate projections with agricultural impact models for Tamil Nadu are urgently needed to quantify future crop yield trends under RCP 4.5 and 8.5 warming scenarios across all agro-climatic zones.
- Longitudinal household panel data: The establishment of a multi-year panel survey tracking the same farm households across sequential hazard events would enable rigorous identification of the determinants of cumulative

resilience erosion and recovery, currently impossible with cross-sectional study designs.

- Gender-differentiated impact analyses: Systematic characterization of differential vulnerability and adaptive capacity along gender lines — particularly for women-headed households and female-managed smallholder farms — represents a critical equity and policy gap in the current literature.
- Compound and cascading event modelling: Mechanistic and statistical models of compound climate event dynamics in Tamil Nadu — including the interaction of

drought, heatwave, and cyclone precursor conditions — would substantially improve multi-hazard risk assessment and early warning system design.

- Economic and food system downstream analysis: Quantification of the downstream supply chain, nutrition security, and rural poverty consequences of documented yield losses — including effects on food prices, dietary diversity, and non-farm rural employment — remains almost entirely absent from the Tamil Nadu-specific literature.

Table 2 Evidence-based farm-level and policy-level adaptation strategies for cyclone, drought, and heatwave impacts on Tamil Nadu agriculture, with reported efficacy estimates and primary literature sources.

Strategy	Hazard Addressed	Crop / System	Reported Efficacy	Reference
Heat-tolerant rice varieties (N22, Sahbhagi Dhan)	Heatwave	Lowland paddy	25–35% yield advantage under heat stress	Kumar et al. (2020)
Cyclone-resistant coconut varieties (VHC-1)	Cyclone	Coconut plantation	40–55% wind damage reduction	Krishnamurthy et al. (2019)
Drip irrigation + deficit irrigation scheduling	Drought	Rice, sugarcane	Water saving 30–45%; yield maintained	Palanisami et al. (2018)
Mulching + green manure (drought)	Drought + heatwave	Groundnut, pulses	Soil temp. reduced 4–6°C; yield +18%	Periyannan et al. (2024)
Crop insurance (PMFBY)	All three types	Multiple	Loss compensation; adoption < 30%	Rajeevan et al. (2018)
Agrometeorological advisories (FAAS)	Cyclone, drought	Multiple	Early warning reduces loss by 12–20%	Narayanan & Balaji (2022)
Farmer producer organizations	All three types	Community level	2× faster recovery post-disaster	Sivakumar & Rengalakshmi (2021)
System of Rice Intensification (SRI)	Drought	Paddy	20–28% water savings; yield maintained	Arulmozhi & Rajavel (2023)

Table 3 Priority research gaps in climate extreme impact and farmer resilience research for Tamil Nadu, with recommended methodological approaches and priority tier.

Research Gap	Description	Recommended Approach	Priority
Climate projection integration	No AR6-downscaled crop impact studies for Tamil Nadu	CMIP6 + DSSAT/ORYZA modelling	Critical
Longitudinal panel data	No multi-year household tracking datasets	Panel survey (5+ year)	Critical
Gender-differentiated impacts	Female farmers underrepresented in studies	Gender-disaggregated survey design	High
Compound event modelling	No mechanistic compound hazard framework for TN	Multi-hazard probabilistic modelling	High
Economic downstream analysis	No supply chain / nutrition security estimates	CGE modelling + nutrition surveys	Moderate
Interior zone coverage	Dry zone districts understudied	Expand geographic scope of field studies	High

VI. CONCLUSION

This systematic review of 33 peer-reviewed studies published between 2017 and 2026 provides a comprehensive and methodologically grounded synthesis of the impacts of cyclones, droughts, and heatwaves on agricultural productivity and farmer resilience in Tamil Nadu. The evidence assembled is unambiguous in its central message:

Tamil Nadu agriculture faces an intensifying multi-hazard climate environment in which the traditional coping strategies of risk-sharing, seasonal diversification, and post-event recovery are being overwhelmed by the increasing frequency, severity, and co-occurrence of major climate extreme events.

The productivity losses documented are substantial — cyclone-induced damages exceeding 50% for plantation crops, drought-driven yield deficits of 35–50% for rain-fed rice, and heatwave-related reductions of 30–38% for heat-sensitive crops at vulnerable phenological stages — and their combined economic impact on farm household incomes is compounded in ways that the current agricultural insurance and relief architecture is structurally unable to address. The emergence of compound events as a distinct and disproportionately damaging risk category represents perhaps the most important single finding for disaster risk reduction policy.

Farmer resilience, while real and demonstrable among larger, better-resourced, and more institutionally connected households, is distributed with marked inequity across Tamil Nadu's farming population. Marginal and smallholder farmers — who constitute the numerical majority — exhibit resilience deficits across all dimensions assessed: economic capacity, social capital, institutional access, technology adoption, and climate awareness. Addressing this resilience deficit requires not only technical agricultural interventions but also structural investments in rural social infrastructure, gender-inclusive extension, and reformed risk financing mechanisms.

For the scientific community, the review surfaces a set of urgent research priorities centred on climate projection integration, longitudinal vulnerability tracking, gender-differentiated analysis, and compound event modelling. For policymakers and development practitioners, the evidence base presented here provides a rigorous foundation for designing a new generation of climate-smart agricultural programmes in Tamil Nadu — ones that are calibrated to the actual multi-hazard, multi-season, socially differentiated risk landscape that Tamil Nadu's farmers inhabit, rather than the idealized single-hazard, single-season model that has historically dominated policy design.

Tamil Nadu's agricultural heritage, cultural significance, and food security role are inseparable from the resilience and adaptive capacity of its farming communities. The scientific and policy challenge of the coming decade is to ensure that both the knowledge base and the institutional frameworks needed to sustain that resilience keep pace with the accelerating pace of climate change.

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